AGRONOMY AS A SCIENCE:
A NEW COURSE FOR BEGINNING AGRONOMY MAJORS

A TEACHING MANUAL SUBMITTED TO THE DEPARTMENT OF AGRONOMY AND SOIL SCIENCE OF THE UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

AGRONOMY AND SOIL SCIENCE

AUGUST 1976

By

James Lee Ingamells

Advisory Committee:

Duane P. Bartholomew, Chairman
S. Arthur Reed
Haruyoshi Ikawa

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AGRONOMY AS A SCIENCE

A STUDENT MANUAL

FOR AGRONOMY 101

CONTENTS

INTRODUCTION

ABOUT THE COURSE AND THE MANUAL

UNTIL 1975, Agronomy 201 (Principles of Tropical Agronomy) at the University of Hawaii was taught as a four-credit, introductory, lecture-laboratory course. Several concerns led to a departmental endeavor to reorganize the laboratory activities and modify their presentation to more effectively suit the needs of beginning agronomy majors. A new course, Agronomy 101 (Agronomy as a Science) was thus instituted to allow for alternative forms of relevant and effective activity-oriented instruction designed to provide students with background experience for later studies in soil and crop science. This manual and the student workbook it contains are an outgrowth of the first two offerings of the course. The development of the course and the features of the manual are discussed in this Introduction.

DEVELOPMENT OF AGRONOMY 101

Initial Concerns

Agronomy 201 at the University of Hawaii is a sophomore-level course designed to introduce both majors and nonmajors to the principles of tropical agronomy. In the fall semester of 1975, the laboratory portion of the course was separated and reinstituted as a freshman-level, activity-oriented course designed primarily for beginning agronomy majors. The new course, Agronomy 101, was initiated in response to two general concerns.

The first concern related to the facilities and assistance that were necessary to handle a large number of students having a diversity of interests, backgrounds and abilities. Increased enrollments in Agronomy 201 and no additional instructional support made it impossible to continue the laboratory sessions as an integral part of the course. Moreover, the diversity of students enrolled raised serious doubts about the relevance of a unified set of laboratory activities where no provisions could be made to reach students on an individual basis in the laboratory.

The second concern related to the curriculum requirements laid out for the agronomy major. A large fraction of the enrollment in lower division soil and crop science courses at the University of Hawaii is represented by students having more than lower division experience. These include graduate students fulfilling minor requirements, upperclassmen and graduate students from other fields of study, and students having some vocational experience with crops. The beginning student who enters these courses with only Agronomy 201 as his background is at a distinct disadvantage in terms of his competetive ability.

Agronomy 101 was, therefore, developed as a freshman-level, preparatory course designed primarily for students with limited agricultural experience and no background in agricultural science. The course was designed to introduce, in a learn-by-doing environment, some of the principles of soil management for crop production, some of the characteristics of crop growth and development, and some of the fundamental aspects of agronomic research. Two types of activity-oriented instruction were employed: structured study and independent study. "Structured Study Sessions" and "Independent Study Assignments" were prepared for this purpose. The educational features of both and the rationale for their development are introduced below.

Development of Structured Study Sessions

Laboratory and field activities are particularly important in agronomic education because they familiarize students with actual agronomic practices and allow them to develop manipulative skills that cannot be developed in lecture, in discussion or by reading. Gagne (1970) discussed the fundamental importance of the laboratory as a means of providing objects and events for instruction. He wrote:

> Although instruction comes to depend heavily of verbal communication, the words merely "stand for" things that may be directly observed. This is the

> fundamental reason why scientists place such a high value on the laboratory and the field exercise. Scientific knowledge depends ultimately on the direct observation of things and events. (page 351)

The Agronomy 201 laboratory and field activities were, indeed, considered a vital part of the agronomy curriculum and became the basis for the development of the Structured Study Sessions for Agronomy 101. The activities were restructured and organized into a set of self-introductory and self-contained units of instruction. Each unit was designed for a three-hour session. Student evaluations and careful assessments of instructional effectiveness during the first two offerings of Agronomy 101 led to refinements in the design and presentation of each unit. The Structured Study Sessions outlined in Section One of this manual represent eight of the most successful units that were developed. Three provisions were largely responsible for their success as an alternative means of introductory instruction; namely, limited enrollment, behavioral objectives, and inquiry-oriented activities.

Limited Enrollment:

The Structured Study Sessions for Agronomy 101 were designed to accommodate a maximum of 20 students. Enrollment in the course was limited to beginning agronomy majors and to interested nonmajors on a space-available basis. Limiting the enrollment to students having a common interest afforded a high degree of student-instructor interaction and allowed the instructor to direct students efficiently and effectively through the structured activities. McKeachie (1969) discussed the importance of small classes as a means of making instruction more "student-centered" and thereby promoting long-term retention of material, critical thinking, and changes in attitude and motivation. As expected, students indicated in a post-instruction survey that the small class enhanced individual learning. Moreover, it was felt that many of the positive responses of students to the course and to the teaching methods that were used were, in part, attributable to the size of the class. The limited enrollment also afforded a means allowing students the opportunity to meet several resource personnel who were called on to assist with some of the sessions.

Behavioral Objectives:

A behavioral objective is a statement that describes, in measurable terms, what an instructor hopes a student can accomplish as a result of a given activity or set of activities. Following the suggestions of Mager (1962) and Andersen (1969), behavioral objectives were used to guide the planning, presentation and evaluation of the instructional activities for each session.

In planning each session, behavioral objectives were first written to specify two things: 1) The type of activities that could best "teach" the desired material during a three-hour session. 2) The performances that the student should be able to demonstrate by the end of the session. Since a principle instructional concern was the provision of relevant and effective learning activities, a limited number of closely related objectives were prepared. The objectives were followed as closely as possible to avoid the inclusion of impertinent activities and to eliminate irrelevant or loosely related material.

In presenting each session, the written objectives served to introduce the student to the instructional activities and allowed him to pace and evaluate his own learning. Since the student was provided with the same objectives that were used to plan the session, his attention was easily focused on the performances that were expected of him. The objectives were also written to include a statement indicating the overall purpose of the instructional activities. This statement was written to specify, in behavioral terms, a relevant application of the principles, concepts and practices introduced in the structured activities.

In evaluating the learning activities, the written objectives were used by the instructor as a check-list of student performances. Those objectives that were actually achieved (i.e.; performances actually exhibited by the students) served as criteria for assessing instructional effectiveness. The ease with which students achieved the objectives and their overall evaluation of the instructional activities were also considered. Those objectives that were not achieved were carefully reviewed along with their respective activities, and necessary revisions were made to more effectively "teach" the desired material. The objectives thus served as criteria for instructional improvement.

Inquiry-oriented Activities:

An inquiry-oriented learning activity can be defined as an activity in which a student's curiosity is aroused to the extent that he is led to solve a problem or arrive at a concept on his own (Romey, 1968; Postlethwait, 1972). Such an activity leaves the student to find his own procedure to achieve the objectives laid out. It is usually compared with the more traditional laboratory (and field) activity in which the student is led by a prescribed procedure through a demonstration-, illustration-, or familiarization-oriented exercise. While traditional laboratory activities are useful to certain types of instruction, their usefulness is limited by their tendency to lead the student as a "passive" participant. The instructor, in turn, is offered little assurance that the performance exhibited is truly representative of the learning intended.

Inquiry-oriented activities were included in the Structured Study Sessions for Agronomy 101 for three reasons: 1) To involve the student as an "active" participant in the realization of the concepts and principles introduced in the course. 2) To free the instructor from the task of introducing concepts and principles by way of lecture and thus allow him to direct students on a more individualized basis. 3) To promote the development of investigative skills which are an integral part of agronomic research and discovery and include making hypotheses, measuring and controlling variables, collecting and tabulating observations, making graphs, and interpreting results.

A well known disadvantage of inquiry-oriented instruction is that it often requires considerable time and effort to lead the student to the realization of a concept or principle. Often, the extra time and effort are not warranted and traditional illustration-, demonstration-, or familiarization-oriented activities are more appropriate. For this reason, each session was designed to include a balance of inquiry-oriented and traditional laboratory or field activities. The The traditional activities were presented to the student as prearranged events or demonstrations, as a set of materials for an illustrative test or experiment, or as a familiarization-oriented procedure designed to acquaint the student with a fundamental practice or technique. Inquiry-oriented activities were carefully linked to the traditional activities by question or problem sets or by exercises designed to lead the student to apply certain investigative skills.

Development of an Independent Field Research Project

Structured learning activities are, by definition, largely direction-oriented; that is, they are designed to lead the student to develop a "particular" skill, to find a "correct" answer, or to familiarize the student with a "fundamental" practice. Gagne (1963) contended that higher levels of inquiry-oriented instruction must be achieved if students are to become familiar with the nature of scientific research and the processes by which scientific information is generated and transmitted. Postlethwait, et. al. (1972) suggested that the highest level of inquiry-oriented instruction is represented by an open-ended research activity in which the student is involved in a complete sequence of steps representative of scientific research; namely, recognizing and defining a problem suitable for investigation, conducting a literature search and review, proposing a solution to the problem, designing and conducting an experiment to test the solution, collecting and interpreting the results of the experiment, drawing appropriate conclusions, and writing a report of the investigation. The rationale for including such an activity as part of the undergraduate curriculum was eloquently given by Holt, et. al. (1969) who wrote:

> All students, whether headed toward research or not, need to develop attitudes toward the certainty and utility of science, the real meaning of scientific hypotheses, the strengths and limitations of scientific approach, and the value of public support for research. (page 1105)

Scientific research is an important part of agronomy; yet an undergraduate's perspective of agronomy is often limited to a set of isolated topics and experiences that are presented in texts, in lectures and in "structured" activities. Agronomy 101 was therefore designed to include an open-ended field research project as a major activity. Following the suggestions of Thornton (1972), Thomson (1972) and Lacy and Funk (1972), the project was presented to students in the following way:

Students were informed from the start that they were to identify a problem of special interest to them, that they were to carry out an independent library and field investigation of the problem, and that they were to write a report of the investigation following the format of the reports found in Agronomy Journal and Crop Science. Two Structured Study Sessions were devoted to training students to begin their investigation. Preparatory activities included a discussion of problems of current agronomic interest, an exercise in formulating hypotheses, a library workshop, and instruction in the design and layout of field plots. Students were also presented with a list of general research topics for which a wide range of problems could be identified for investigation.

To assure meaningful and "active" student involvement, each student was given the responsibility of identifying his own research problem. Consultation hours with the instructor were arranged to help the student in this regard. For those students who felt they had no topic of "special" interest, a planting density experiment was conducted as a group project. However, within the scope of the density experiment, each student was required to identify a problem and carry out an independent investigation. Examples of problems that were investigated during one semester in a planting density experiment with corn included the following: What is the effect of planting density on tillering? What is the relationship between dry matter production and planting density? Does planting density affect the number and weight of ears produced per plant? Are plant and ear height affected by planting density? Thus, a large number of independent investigations were possible for a single experiment. Students who shared an interest in a topic of their own choice were also permitted to conduct a group experiment, provided each student identified a different problem.

Students were not restricted in any way to suggested areas of research. Student investigations were limited only by their relevance to agronomy, by the time, space and materials available for the field experiment, and by the student's own imagination and investigative energy.

During the course of a semester, arrangements were made to provide students with additional orientation and training when needed. Supplementary sessions included films, field trips, guest speakers, and a student symposium. Field trips to local agricultural sites allowed students to witness actual field operations and to discuss with farm managers some of the problems associated with field crop production. Other sessions dealt with weed control methods, irrigation techniques, and data collection. A student symposium at the end of the semester was especially useful in helping students communicate the results of their independent study and allowed for a critical discussion of the research projects. The independent research project and the supplementary sessions provided a network of instruction that was highly regarded by the students.

During the independent investigations, the instructor was an advisor whose primary responsibilities were: 1) To help each student formulate a working hypothesis for his experiment. 2) To plan with the student the methodology needed to test the hypothesis. 3) To assist the student with a literature search and review. 4) To guide the student toward the completion of a final report. A set of Independent Study Assignments was prepared to assist the instructor in this regard. Each assignment directed the student to complete a given phase of his investigation and to document relevant information. One assignment was due every three weeks. The assignments proved to be a vehicle for valuable student-instructor interaction since the completed assignments were an indication of student progress and could be used by the instructor to offer advice to students on an individual basis. The assignments are given in Section Two of this manual.

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FEATURES OF THE MANUAL

Section One; Structured Study Sessions

Eight Structured Study Sessions are detailed in Section One of the manual. A variety of topics are considered; some are directly related to agronomic research while others are related to the fundamentals of soil and crop science. In view of the limited facilities available for laboratory instruction, the Structured Study Sessions were designed to require a minimum of laboratory space and equipment. In fact, many of the activities are designed for field study or relate directly to field situations. The instructional materials described are all easily obtained and set up. Certain items (eg.; dissecting microscopes) may be in short supply, but arrangements can be made to borrow such items from other departments for the limited time they are needed.

In spite of the efforts made to minimize the technical aspects of offering activity-oriented instruction, many of the activities described in the manual require considerable preparation. Seedlings must be grown, uniformity trials planted, tensiometers installed, soil types collected, appointments with reference personnel made, and so on. Much of the preparation, however, is easily made the responsibility of a hired student-help or a teaching assistant and the activities are described in detail largely for this purpose.

Each Structured Study Session is designed for a three-hour period and is detailed in four parts: 1) Objectives, 2) Instructor's Notes, 3) Worksheet, 4) References and Selected Readings.

Objectives:

The Objectives for each session are given in a format which allows the student to easily pace and evaluate his own learning. A set of "Instructional Objectives" is given first and includes a short statement of the importance of the topic at hand and incidates the type of instructional activities that have been designed for that session. The performances that a student should be able to demonstrate or the skills that he should be able to acquire during the session are carefully enumerated. The student can use the "Instructional Objectives" to prepare himself for the learning activities and to pace and evaluate his progress during the session.

A "Terminal Objective" is given next to indicate what the session was designed to prepare the student for and serves as a general criterion for the student to evaluate his accomplishments. Many of the "Terminal Objectives" are closely related to one of the Independent Study Assignments. Others relate more generally to a fundamental crop management concern.

Instructor's Notes:

These are given for the expressed purpose of guiding the future preparation and presentation of the instructional activities. The pages are identified sequentially by letter (1a, 1b, ...) to facilitate their separation from the manual when it is duplicated for student use. The Instructor's Notes are outlined in three parts: "Materials and Preparation," "Presentation," and "Suggestions."

The "Materials and Preparation" for each instructional activity are described in detail. Those preparations which need to be begun earliest are described first. A timetable for the preparation of activities is, therefore, easily made once a schedule of Structured Study Sessions has been drawn up. A list of instructional materials which must be on hand for the session is also given.

The "Presentation" describes the manner in which the "Instructional Objectives" for the session are best achieved. A suggested amount of time for each activity is parenthetically noted. All the "Presentations" described have been used successfully in the past. Some, however, have been modified to facilitate easier or more effective instruction.

The "Suggestions" emphasize important instructional concerns and provide recommendations for future instruction. A recurring suggestion is that the instructional emphasis be placed on the development of skills rather than on the aquisition of knowledge. Specific activities requiring such emphasis are indicated.

<u>Worksheet</u>:

The Worksheet is for the student's use and provides background information, exercises, and question sets designed to aid the student in accomplishing the "Instructional Objectives." During the development of <u>Agronomy 101</u>, the Worksheets were handed out on a week-by-week basis and subsequently evaluated in terms of their usefulness as instructional aids. Student evaluations led to two basic types of revision before the Worksheets were incorporated in this manual:

First, the background information was cut to a minimum. Much of the information was, in fact, only indirectly related to the "Instructional Objectives" and was too much for students to assimilate in view of their independent study requirements.

Second, the Worksheets were revised to make them as easy to follow as possible. Ambiguous directives and questions were clarified and inductive procedures, many involving interpretations of graphs and tables, were revised to lead more directly to the correct answers or concepts.

References and Selected Readings:

During the first two offerings of Agronomy 101, selected readings were placed on reserve in Sinclair Library. An information sheet was handed out at the beginning of the semester to call students' attention to these readings. They are now more appropriately listed after their respective Worksheet. References used in the preparation of the background material are also listed.

Section Two; Independent Study Assignments

Five assignments are given in this section of the manual. The assignments are collectively intended to lead the student to the completion of a written report of his independent research project. Each assignment relates to a particular phase of the project. The assignments are arranged to help the student complete each phase in a logical sequence during the course of a fifteen week semester.

The assignments begin with a "Project Proposal" that requires the student to formalize a hypothesis for his experiment and to outline his experiental strategy. The second assignment is a set of "Practice Calculations" designed to lead the student through some of the mathematical conversions that are normally encountered in field research and, ultimately, to make calculations related to his own experiment. The third assignment directs the student in the completion of a literature review and a description of his materials and methods. The fourth assignment prepares the student for data collection. The final assignment details for the student the format for a written report of his research.

Presenting the assignments collectively as a part of the manual encourages the student to relate his structured study activities to his independent study requirements. The instructor can easily set dates for the periodic completion of the assignments. The student is thus encouraged to systematically pull his information together for his final report before the end of the semester and is spared much of the "last minute" chore that is often associated with semester reports.

Most important, the assignments are a vehicle for valuable student-instructor interaction. They are intended to be completed in close consultation with the instructor to insure that the student's investigation is brought to a meaningful conclusion.

SECTION ONE

STRUCTURED STUDY SESSIONS

EIGHT Structured Study Sessions have been designed for Agronomy 101. A variety of topics are considered; some are directly related to agronomic research while others are related to the fundamentals of soil and crop science. The topics include:

AGRONOMY AS A SCIENCE

INTRODUCTION TO PLOT EXPERIMENTS

SOIL FERTILITY

PHYSICAL CHARACTERISTICS OF SOILS

SOIL WATER

SEED GERMINATION AND SEEDLING ESTABLISHMENT

FLOWER STRUCTURE AND SEED DEVELOPMENT IN GRASSES AND LEGUMES

PHOTOSYNTHESIS AND PRIMARY PRODUCTIVITY

A set of "Instructional Objectives" and a "Terminal Objective" are provided for each session and should be read carefully before the session begins. A WORKSHEET, composed of background information, exercises and question sets, is also provided for each session to aid the accomplishment of the "Instructional Objectives." For most sessions, a list of REFERENCES AND SELECTED READINGS follows the WORKSHEET.

AGRONOMY AS A SCIENCE

OBJECTIVES:

A) Instructional Objectives:

In agronomy, scientific research is carried out to discover new principles and to develop new concepts that can be used to improve field crop production. The method of scientific research, invariably includes the careful observation of things and events, the formulation of clear and "testable" hypotheses, experimentation to test the validity of the proposed hypotheses, and the interpretation and communication of the experimental results. This is the overall process by which scientific information is generated and transmitted.

A major objective of Agronomy 101 is to involve each student in an independent library and field research investigation. This session is designed to provide the orientation you need to begin your investigation. The instructional activities include a classroom discussion and a library workshop wherein you will be encouraged to:

1) LIST problems of agronomic interest and importance.

2) WRITE a hypothesis for a plot experiment designed to investigate a problem related to a topic of special interest to you.

3) FIND scientific literature related to your hypothesis using one or more of the following:

    a) Bibliography of Agriculture.
    b) Biological Abstracts.
    c) Biological and Agricultural Index.
    d) Field Crop Abstracts.
    e) Tropical Abstracts.

4) BEGIN a bibliography card file of literature citations related to the topic you wish to pursue during the course of the semester.

B) Terminal Objective:

At the end of the discussion and workshop period, you should be able to formulate a hypothesis for a plot experiment and find scientific literature relevant to the hypothesis.

WORKSHEET:

A) Identifying Agronomic Concerns:

Agronomy is the agricultural science that deals with the theory and practice of field crop production. Although agronomy originally referred to the practice of growing grains and forages, today's "field" crops also include sugar, oil, fiber, fruit and vegetable crops. Land management for field crop production and the performance of field crop varieties are the chief concerns of agronomic study.

As a preliminary exercise to your Agronomy 101 studies, use the space below to list some of your own agricultural interests. Indicate which of your interests, in your opinion, represent topics of agronomic concern and explain.

B) Formulating a Hypothesis:

Each and every agronomic experiment must have a well formulated hypothesis.

Webster's Dictionary defines a hypothesis to be a "tentative assumption made in order to draw out and test its logical consequences." In agronomic research, a hypothesis is generally thought of as a tentative answer or solution to a crop production problem. The results of careful experimentation become the criteria for accepting or rejecting the proposed hypothesis.

Consider, for example, an experiment designed to investigate the effect of plant spacing on the productivity of soybean. Plant spacing, incidentally, is a variable of interest in what agronomists refer to as "planting density" or "plant population" studies. The following hypotheses might be drawn for the experiment:

1st Hypothesis: Plant spacing will affect the number of pods produced per plant.

2nd Hypothesis: Increased plant spacing will result in a decrease in the weight of pods produced per unit area of land.

Notice that each of these hypotheses can be either accepted or rejected depending upon the MEASURABLE RESULTS.

Questions:

1) Can you formulate another hypothesis for a planting density experiment with soybean?

For a planting density experiment with corn?

2) Can you formulate a hypothesis for an experiment related to a topic of your own choice?

C) Finding Related Literature:

Any scientific investigation should include a review of the scientific literature. The following periodical indexes are often used to locate literature pertaining to agronomic research.

Bibliography of Agriculture
Biological Abstracts
Biological and Agricultural Index
Field Crop Abstracts
Tropical Abstracts

The listings in the periodical indexes are organized around subject headings. To use the indexes, identify the subject of interest in terms of the EXACT INDEX WORDS used in the subject headings.

Suppose, for example, the effects of planting density on the productivity of corn is the subject at hand. Appropriate subject headings leading to pertinent literature might be "corn," "planting density," and "productivity." However, synonyms and different forms of these words may also be included as subject headings. A few alternative headings are given in the exercise below.

Can you add other synonyms or related index words to the checklist. Study the layout of each of these indexes. Use ONE of the indexes to complete the following checklist.

Index used: ________________________ (Title). ________ (Volume), ________ (Number), ______ (Year).

Possible Subject Heading:	Is the subject heading listed in the index? (yes, no)	If "yes", are pertinent articles listed under the subject headings?
corn	________	________
Zea mays	________	________
maize	________	________
	________	________
planting density	________	________
density	________	________
	________	________
productivity	________	________
yield	________	________
	________	________

D) Making a Bibliography File:

The bibliographical listings given in periodical indexes, in the bibliography of a text, and in the literature cited sections of scientific papers are called citations or references. When a citation is found that might be relevant to the topic you are reviewing, it is always wise to copy down all the bibliographical information concerning the article. A bibliography card can be used for each citation selected. A suggested format for bibliography cards is shown below.

______________________.	______________.	
Author(s) of Article	Year	
______________________________________.		
Title of Article		
______________________.	______________:	__________.
Journal or Text	Volume and Number or Publisher	Pages
__________ __________ __________		
Call No.		
SOURCE: ______________	______ ______ ______	
Name of Index, Text, etc.	Vol. Page Year	

Notice that the source from which an article is found is also included on the bibliography card. In addition to the periodical indexes, card catalogues and the bibliographies of texts and periodical publications are often valuable sources for citations.

Note also that the format can be revised for citations of texts or books. Familiarity with the conventional formats for literature citations is helpful when using bibliography cards.

Bibliography card files are extremely useful, both as a reference file and as an aid to writing scientific reports. Because each card represents one article, the cards can be easily alpabetized by author or easily arranged to follow the subject outline of a paper.

Bibliography cards can be as large as is convenient. Some people prefer cards large enough for an outline or an abstract of each article cited.

INSTRUCTOR'S NOTES:

A) Materials and Preparation:

The materials needed for this session are:

1) pre-instruction survey forms (page 1b).

2) student copies of this manual.

3) slide projector and slides of past Agronomy 101 activities.

Materials which are to be reproduced by Duplicating Services (Room 17, Hawaii Hall) must be submitted for duplication two weeks in advance.

An appointment for a one-hour workshop session with a science reference librarian should be made one week in advance and the librarian given a copy of the Objectives and the Worksheet for this session.

The instructors who are to play a major role in directing the instructional activities during the semester should also be asked to be on hand to meet the students during the opening ½-hour of this session.

B) Presentation (A classroom discussion and library workshop session):

1) Introduction (½ hour):

Pass out the pre-instruction survey forms for completion during the opening minutes of the session. While students complete the forms, the instructors can introduce themselves and explain the nature of the course. Slides can be shown to illustrate:

a) The types of activities included in the course.

b) The plot area available to 101 students.

c) The crops grown by 101 students during previous semesters.

The pre-instruction survey forms can be collected for use in the following activity (continued on page 1c).

Suggested Format for Pre-instruction Survey Form

AGRONOMY 101

Pre-instruction Survey

(Spring/Fall) Semester, 19--

NAME: ______________________________

Name by which you
wish to be called: ______________________

Places where you have
lived (town & state): ____________________

1) DO YOU HAVE...

	YES	NO
A) any agricultural work experience?	____	____
B) any course background in agriculture?	____	____

IF "YES" FOR EITHER, BRIEFLY DESCRIBE.

2) HAVE YOU EVER TAKEN A COURSE FOR WHICH...

A) you actively participated in DESIGNING an experiment?	____	____
B) you wrote a report of an experiment complete with an introduction, a description of the materials and methods, and an interpretation of the results?	____	____

IF "YES" FOR EITHER, BRIEFLY DESCRIBE.

3) WHAT IS YOUR OBJECTIVE IN TAKING AGRONOMY 101?

B) Presentation (continued)

2) Discussion -- Instructional Objectives 1 & 2 (½ hour):

Open the discussion by defining "agronomy." At this point in the course most students will be interested in what distinguishes agronomy from other agricultural sciences. Involve the students in the discussion as quickly as possible by having them mention some of their own interests in agriculture. Refer to item #1 of the completed surveys to stimulate contributions from those who indicated they have some agricultural experience or background.

Discuss the necessity for formulating clear hypotheses in scientific research. Emphasize that a hypothesis must be written in terms of MEASURABLE observations which describe the test that is to be performed.

3) Workshop -- Instructional Objectives 3 & 4 (1 hour):

The science reference section of the Hamilton Library can be used to conduct the workshop for this session. The sole purpose of the workshop is to show students how to begin a review of the literature using selected agricultural indexes. The third and fourth Instructional Objectives should be followed as closely as possible. Planting density is a most appropriate sample topic for this workshop. (Worksheet; pages 4 & 5).

The following points are likely to be covered in completion of the third Instructional Objective:

a) The location of the indexes.

b) How to find the subject of interest in a given index.

c) The importance of recording all the essential bibliographical information in each and every citation.

d) How to find the accepted abbreviation for a given journal; and how to find a complete title for a given abbreviation.

e) How to find the call number of a journal of interest.

A sample bibliography card (Worksheet; page 5) can be completed as the last activity of the session.

C) Suggestions:

Use of the pre-instruction survey during the first class session is strongly recommended for several reasons.

First, items #1 and #2 of the survey refer to the principal concerns of the course itself. That is, the course hopes to introduce students to agricultural (agronomic) experiences and is designed to allow students to apply the scientific method in pursuit of these experiences. The survey thus allows each student to evaluate his own educational objectives in terms of the background the course hopes to provide.

Second, the survey facilitates getting to know the students early in the semester. Because the survey helps to identify student backgrounds, students who are beyond the level of the introductory material offered in the course can be identified and asked to consider (or reconsider) their reasons for taking the course. For example, Horticulture students who have taken or intend to take Horticulture 364 may find Agronomy 101 considerably less valuable than would a beginning Agronomy and Soil Science major.

Third, the information in the survey can be immediately used to initiate a class discussion, as mentioned on page 1c. Students with some agricultural background can be called on to give examples of problems they are familiar with. Alternatively, students with no background can be called on to speculate on local agricultural problems in the area where they live. Interests which are expressed in the survey may well be the beginnings of an independent study project.

The time factors involved during this session must be handled carefully. Introducing the course in terms of its origin, history, and intent tends to be time consuming and discussion here should be minimal. However, a discussion of how the course is unique as a freshman level course is important and slides illustrating past activities stimulate the interest and involvement of the students.

The discussion of a hypothesis should not belabor the philosophy behind making hypotheses; nor should specific formats for hypotheses (eg.; null hypotheses, if-then statements, etc.) be emphasized. The important point to get across is that a hypothesis is a tentative answer to a question or a proposed solution to a problem.

C) Suggestions (continued)

It is recommended that only one hour be used for the library workshop. The specific objectives for the workshop should be followed closely. Although many topics must remain untouched in one hour's time, the deliberate accomplishment of the selected objectives is enough to help students begin a literature search of their own.

A literature review is required of each student in completion of his final report. The success of his literature research will depend on both the student's own skills and the nature of his topic. Questions which arise while searching for literature can be answered by both a reference librarian and the instructor in charge of the course. Students should be encouraged to call on these persons when doing library research.

A file of reprints related to possible student topics, including planting density, should be on hand with the instructors to aid and encourage students who have trouble locating relevant information. The instructors can also discuss with students during their independent study time the utility of bibliography card files. Instructors can, perhaps, show one of their own card files to consulting students and demonstrate how a file can be organized by both author and by subject.

It should be kept in mind that many 101 students are unfamiliar with proper citation formats for scientific literature. Furthermore, many students must be reminded to include ALL the essential bibliographical information in EACH AND EVERY citation.

As a final suggestion, the time available immediately following the workshop can be used to consult with students regarding topics they wish to pursue during their independent study. The library is, perhaps, the ideal place to help students clarify their interests and find background information for their topic. (SEE INTRODUCTION TO PLOT EXPERIMENTS: page 1a.)

INTRODUCTION TO PLOT EXPERIMENTS

OBJECTIVES:

A) Instructional Objectives:

In agronomic research, plot experiments are often used to investigate field management factors and to evaluate the performance of new crop varieties. During a combined discussion and field study session, a plot experiment will be begun as a class project. The experiment will be a study of the effect of plant spacing on crop performance and is hereafter referred to as the "planting density experiment." Those who are interested in participating in the experiment will have available as their planting material a locally developed variety of either corn (*Zea mays*) or soybean (*Glycine max*).

Students may pursue an independent experiment as an alternative to the planting density experiment. However, only the planting density experiment need be layed out during this session. Since the techniques which will be introduced are basic to all field and plot experiments, students doing independent experiments will also benefit from the activities of this session.

The plot experiments for *Agronomy 101* will be carried out at the Magoon Experiment Station on the Mauka Campus of the University of Hawaii in Manoa. A map of the location of the Magoon facilities is given on page 2.

To begin a plot experiment, you should be able to:

1) IDENTIFY several controllable and uncontrollable variables which are characteristic of the plot area and may affect the results of the experiment
and
DESCRIBE how these variables can be measured and/or controlled.

2) LIST the treatments of a possible single-factor plot experiment and
SKETCH a randomized complete block design for the experiment.

3) DETERMINE the required dimensions of the experiment
and
INSTALL the experiment in the plot area available.

B) Terminal Objective:

At the end of the field study session, you should be able to lay out and plant a plot experiment according to a specified randomized complete block design.

WORKSHEET:

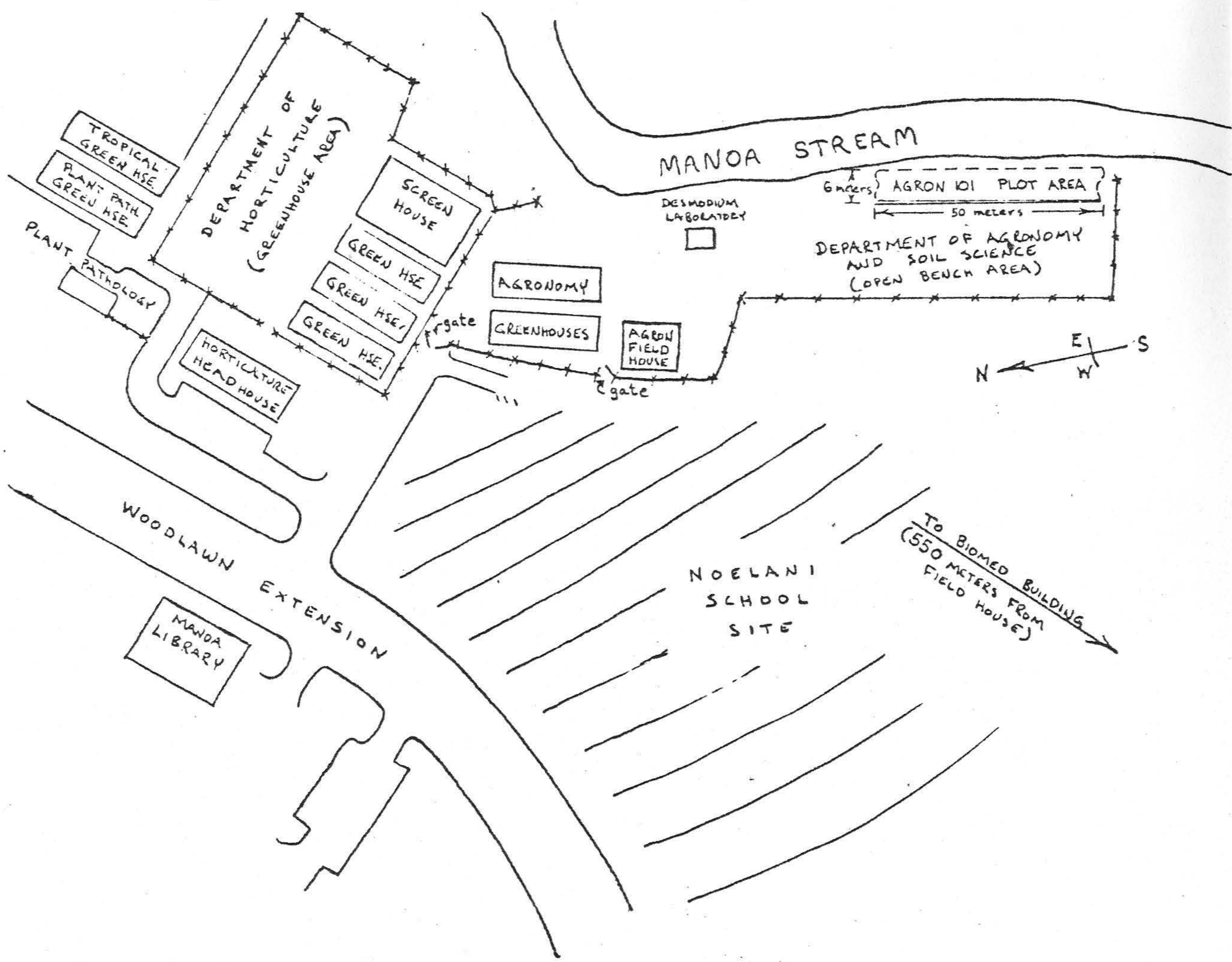
A) The Location:

The Agronomy 101 plot experiments will be conducted at the Magoon Experiment Station on the Mauka Campus of the University of Hawaii in Manoa. The area which is available is a level area adjacent to a steep Manoa Stream bank.

Figure 1

Magoon Experiment Station

University of Hawaii, Manoa



WORKSHEET:

B) The Variables:

A number of controllable and uncontrollable factors can affect the results of any experiment. This is especially true in plot studies where many soil and environmental factors play important roles in determining the growth of a crop. In your plot experiment, you will have to control several of these factors in order to carry out a meaningful experiment.

The factor of principle interest in the "planting density experiment" is plant spacing. The supposed effect or effects of this factor should be written into the hypothesis for the experiment. Plant spacing is both a measurable and a controllable variable in the experiment. Because plant spacing is the only variable which is being tested, the experiment is called a "single-factor" experiment. More than one factor may be investigated in an experiment, but "single-factor" experiments are the easiest to handle.

Factors other than plant spacing are certain to affect the growth and productivity of a crop. These must be given careful consideration in the planting density experiment so that they do not interfere with the test the experiment proposes to perform. It is especially important to consider which factors might vary within a plot and thereby produce undesirable differences in growth and productivity; that is, differences which are not attributable to planting density. It is also important to consider the factors which vary from plot to plot, from field to field, and from season to season and thereby produce different results should the experiment be repeated in a different area or at a different time.

It is helpful in plot experiments to list the factors which might affect the results and to describe how these factors should be measured and controlled. The next page is intended as an exercise in this regard. Choose or formulate a hypothesis for a single-factor plot experiment. Enter the single-factor involved (i.e.; the variable to be tested) as the first entry in the list. Indicate how it will be measured and controlled. Complete the list with those factors which you feel must be controlled so that they do not interfere with the variable being tested. A few entries have been made to serve as a guide.

List of Important Factors in a Single-factor Plot Experiment

	Factor	Measurement:	Control:
1	______________ (variable being tested)		
2	Applied Fertilizer	Recommended weights of N, P, & K (kg/ha)	Uniform banding & side dressing
3	Applied Water	Uniform volumes (liters); if possible	Uniform sprinkler or drip application
4	Soil Fertility	Available N, P & K (ppm); from soil analysis	Uniform tillage & pH; supplementary fert.
5	Rainwater	Rain gauge (cm)	Flat plots, good drainage
6			
7			
8			
9			
10			
11			

B) The Variables (continued)

Questions:

1) Some of the most beneficial agronomic experiments are carried out in commercial fields. Sometimes a simple, single-factor experiment can be one of the most worthwhile investments a farmer (or an industry) can make. What might be an example?

2) Why are single-factor experiments especially adaptable to commercial fields?

C) The Design:

The design of a plot experiment is based, in part, on the number of factors (variables) under investigation. Each of these factors is divided into treatments or treatment combinations. In the planting density experiment, for example, only one factor is under investigation -- plant spacing. The number of different spacings included in the experiment determines the number of treatments.

Applied fertilizer is another example of a factor which can be divided into several treatments. Nitrogen fertilizer, for instance, can be applied at three different rates to form three different treatments. If more than one factor (eg; nitrogen plus phosphorus) is involved, the treatments of one factor must be combined with the treatments of the additional factor(s), and thus, various treatment combinations arise.

Questions

1) Suppose you wanted to investigate the effect of a second factor in the planting density experiment. For example; three varieties of sweet corn might be tested at three different planting densities. With these two sets of treatments, how many different treatment combinations are possible?

2) Suppose a third factor, such as the level of applied nitrogen, is included in the experiment. How many different treatment combinations are possible?

You see then, how unwieldy an experiment can become if many factors are included in the investigation, especially when you consider that each of the treatment combinations must be replicated (page 7).

C) The Design (continued)

In agricultural experiments, it is virtually impossible to control all of the factors which might affect the results. Indeed, there are even factors which act in unknown or unpredictable ways, and the experimentor is never 100 percent sure that the results of his experiment are truly due to the primary factors under investigation. It is, therefore, important to design plot experiments with several things in mind.

First, all treatments must be replicated. Because of the variability which results from uncontrolled factors, no single measurement of a treatment effect is reliable. The reliable representation of a treatment effect depends on replicated measurements, from which an average value can be derived. The results of a good experiment are, in fact, averages of treatment effects. In general, the more replicates that are used, the more reliable are the results.

Second, the number of factors under investigation should be kept to a minimum. Although experiments can be designed to investigate many factors at one time, the resources, such as land, labor and materials, are usually limited in plot experiments. Furthermore, available resources are often best used by making as many replications as possible, rather than by including additional factors.

Third, it is imperative that factors not under investigation be kept as honogeneous as possible within each replicate. This is a common sense precaution which must be taken to insure meaningful results.

Fourth, precaution should be taken to prevent the "biased" assignment of treatments or treatment combinations to the plots of an experiment. Each treatment must have an equal chance of being assigned to any one plot. Hence, treatments are assigned at random to specified plots in a replication. They must not be assigned in a systematic manner! Random assignment of treatments is especially necessary if the experimental results are to be analyzed by statistical methods.

Randomization is an easy procedure to carry out in plot experiments. A table of random numbers is commonly used to assign treatments to various plots. Other methods can be used, such as drawing numbers from a hat, each number representing a certain treatment.

C) The Design (continued)

A table of random numbers is given below. To use the table, choose any place as a starting point for selecting numbers; such as the last three digit number in the third line of the second column (756); or the single digit number furthest to the top left-hand corner of the table (5). Then move in an orderly fashion, either across the row or along the column, and write the numbers in the order that they appear.

Suppose single digit numbers less than five are desired in random order. Using the top right-hand corner as a starting point, the desired numbers appear down the column in the order 3, 3, 2, 1, 1, 0, 4, 1. The five digits represented here are also in the non-repeating order 3, 2, 1, 0, 4.

Remember: Numbers must be chosen from the table in the order that they appear. They must not be chosen in an irregular or haphazzard fashion as this may result in "biased" selection.

Table of Random Numbers

54463	22662	65905	70639	79365	67382	29085	69831	47058	08186
15389	85205	18850	39226	42249	90669	96325	23248	60933	26927
85941	40756	82414	02015	13858	78030	16269	65978	01385	15345
61149	69440	11286	88218	58925	03638	52862	62733	33451	77455
05219	81619	10651	67079	92511	59888	84502	72095	83463	75577
41417	98326	87719	92294	46614	50948	64886	20002	97365	30976
28357	94070	20652	35774	16249	75019	21145	05217	47286	76305
17783	00015	10806	83091	91530	36466	39981	62481	49177	75779
40950	84820	29881	85966	62800	70326	84740	62660	77379	90279
82995	64157	66164	41180	10089	41757	78258	96488	88629	37231
96754	17676	55659	44105	47361	34833	86679	23930	53249	27083
34357	88040	53364	71726	45690	66334	60332	22554	90600	71113
06318	37403	49927	57715	50423	67372	63116	48888	21505	80182
62111	52820	07243	79931	89292	84767	85693	73947	22278	11551
47534	09243	67879	00544	23410	12740	02540	54440	32949	13491
98614	75993	84460	62846	59844	14922	48730	73443	48167	34770
24856	03648	44898	09351	98795	18644	39765	71058	90368	44104
96887	12479	80621	66223	86085	78285	02432	53342	42846	94771
90801	21472	42815	77408	37390	76766	52615	32141	30268	18106
55165	77312	83666	36028	28420	70219	81369	41943	47366	41067

Photocopy from Snedecor, G. W. & W. G. Cochran. (1967). Statistical Methods. Sixth Edition. Iowa State University Press. p 543.

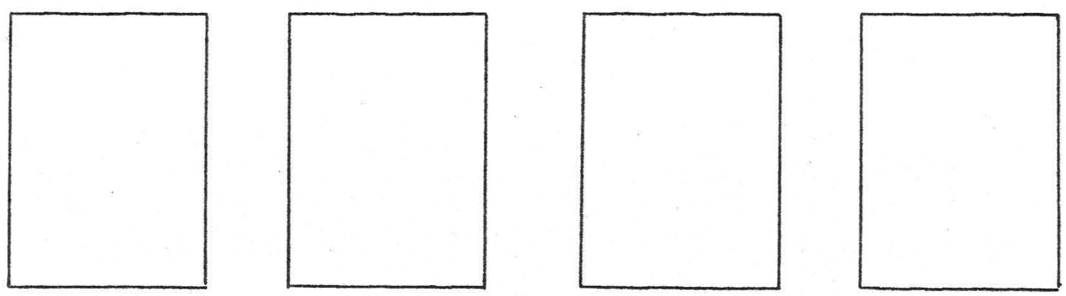
C) The Design (continued)

One of the simplest and best known experimental designs is the "randomized complete block design." The "blocks" refer to replicated areas of equal dimensions each containing a complete set of treatments. A randomized complete block design will be used for the planting density experiment as this design is particularly illustrative of the importance of both replication and randomization in agronomic field research.

List the treatments which will be used in the plot experiment of your choice and assign a number to each treatment.

Now suppose that the four blocks shown below represent replicates of a randomized complete block design. Divide the blocks into the same number of "plots" as there are treatments in your list above. Assign a complete set of treatment numbers (above) IN RANDOM ORDER to the plots within a single block. Repeat the randomized assignment of treatments for each of the remaining blocks.

Rep. I Rep. II Rep. III Rep. IV



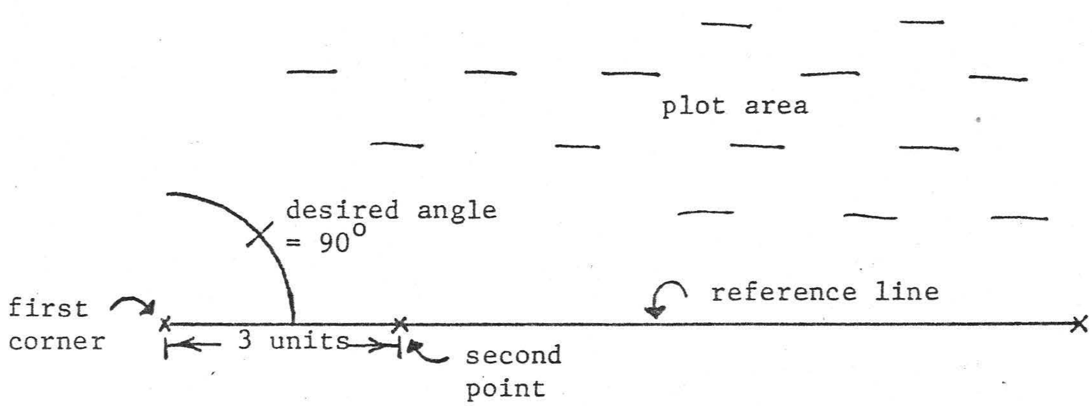
Before designing a plot experiment, a preliminary study of the plot area must be made to determine the dimensions and arrangement of the blocks. Identify those conditions (variables) which should be controlled by blocking and indicate in your field-book what those conditions are. Remember: The conditions within each block must be as homogeneous as possible (page 7) so as not to obscure the true effect of the treatments.

D) The Layout:

Laying out the plots for an experiment must be carefully done so that they follow precisely the specifications of the experimental design. Some simple surveying techniques are used to lay out plots in the field. Since most designs specify rectangular plots, a technique for squaring corners is given below.

The layout for a rectangular plot is begun by measuring and staking a single edge from a chosen corner of the area available. Two stakes are needed to define this edge. The line defined by these two stakes is the reference line for the first corner of the intended plot.

Figure 2



A right (90°) angle can be made at the site of the first corner by constructing a Pythagorean triangle. Such a triangle has its longest side (the hypotenuse) directly opposite its right angle. The two shorter sides of the triangle form the right angle itself. The length of the hypotenuse is given by the formula.

$$h^2 = a^2 + b^2,$$

where h is the hypotenuse and a and b are the two shorter sides.

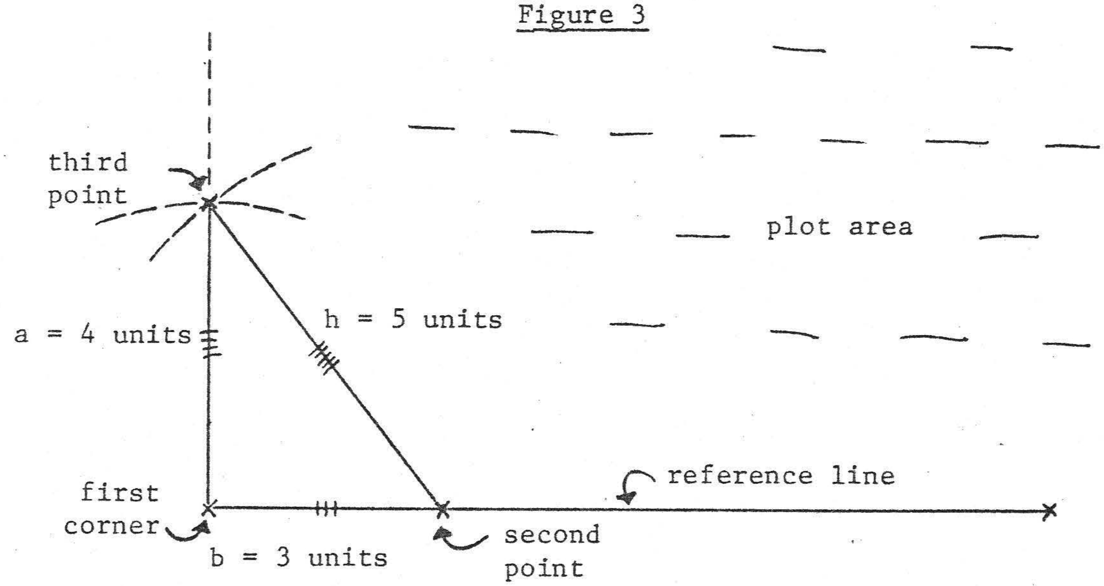
A combination of numbers which easily fits this formula is $h = 5$, $a = 4$, and $b = 3$. Thus, a 5 x 4 x 3 triangle can be staked out such that the right angle coincides with the first corner of the plot. This is done as follows:

The reference line is first segmented to obtain one of the shorter sides of the Pythagorean triangle. A stake is placed PRECISELY ON THE REFERENCE LINE AT A MEASURED DISTANCE FROM THE FIRST CORNER. Suppose this distance is three units. Two points of the triangle are thus fixed at either end of this 3-unit segment. The location of the second point with respect to first corner of the plot area is shown in Figure 2 above.

D) The Layout (continued)

The third point of a Pythagorean triangle is usually found in the field by making two intersecting arcs whose radii extend from the first corner and from the second point of the triangle. String or a tape measure can be used to mark these arcs in the manner in which a drawing compass is used. Figure 3 shows the intersection of two arcs drawn with radii measuring a = 4 units from the first corner and h = 5 units from the second point. The intersection defines the third point of the Pythagorean triangle and effectively "squares the first corner" of the plot area.

Figure 3



After the third point is staked, the first corner can be used to extend the edges of the plot area in either direction by aligning stakes at extended distances from either the second or third point. Additional corners can then be made at desired locations.

A check on the precision with which a plot is layed out is made when the plot area is closed at the fourth corner. If the corners are square, the area will form a perfect rectangle and the sides will measure true.

D) The Layout (continued)

Questions:

1) Suppose the total area of a plot experiment is contained within a square measuring 30 meters on a side. What is the length of the diagonal of the plot area?

2) Could a 10 x 8 x 6 meter triangle be used to lay out a square plot measuring 30 meters on a side?

3) Suppose a 3 meter side of a plot is staked out and a 9-meter tape measure is available. Instead of making intersecting arcs to identify the third point of the 5 x 4 x 3 meter triangle, what other procedure could be used?

REFERENCES AND SELECTED READINGS:

Alder, H. L. and E. B. Roessler. (1972). Introduction to Probability and Statistics. Fifth Edition. W. H. Freeman. 373 p.

Little, T. M. and F. J. Hills. (1975). Statistical Methods in Agricultural Research. Second Printing. University of California Agricultural Extension Service. 242 p.

INSTRUCTOR'S NOTES:

A) Materials and Preparation:

Two months prior to this session, the plot area at Magoon should be tilled and a uniformity trial planted.

One week prior to the session, the following materials should be checked out or arranged for with the technician in charge at Magoon:

1) Fertilizer (epsom salt, treble superphosphate, urea, muriate of potash, and zinc sulfate).

2) Seed (local variety of soybean and an early maturing variety of corn) in quantities large enough for both the planting density experiment and the independent projects.

3) Seed planters.

4) Low-horsepower tractors for tillage and incorporation of fertilizer.

Students are to meet with the instructors at their own convenience prior to this session. Topics of student interest are thus surveyed and the resources and limitations of the Magoon Station discussed. Helping students clarify their interests and encouraging them to formulate hypothesis is an important part of the preparation for this session. (See Suggestions; page 1d.)

A) Materials and Preparation (continued)

The final preparation includes informing the Magoon personnel of the scheduled class activities, weighing out the fertilizer needed for each replicate of the planting density experiment, and collecting the following materials as part of the Agronomy 101 supplies for use by students at Magoon:

1) Large stakes or steel rods to identify the corners of the plot area experiments.

2) Surveyor's tape (two or three rolls of different colors).

3) Meter tape measure (one 30-meter).

4) Meter sticks (several).

5) Treatment stakes for labeling plots within student experiments (100 or more).

6) Soft-lead marking pencils for marking treatment stakes.

7) String (1,000 meters).

8) Rakes and hoes (many).

9) Large (20-liter) plastic pots for mixing fertilizer (one per replicate of the planting density experiment).

Bring a copy of J. W. Purseglove's Tropical Crops Monocotyledons and of Purseglove's Tropical Crops Dicotyledons to class. Paperback editions are available in the U. H. Bookstore. Copies should also be available under the care of the instructor for use by students during the semester.

B) Presentation (A classroom discussion and field study session):

1) Introduction (½ hour):

The opening minutes of the session can be used to list the topics proposed by students during their independent meetings with the instructor. It should be pointed out that although the Instructional Objectives for this session apply for any plot experiment that might be conducted, only the planting density experiment need be installed at this time. Emphasize that hypotheses must be clearly formulated for the independent plot experiments before they can be layed out.

Point out that soybean and corn are available for the planting density experiment. These are crops of world-wide agronomic importance, are suitable for the conditions at Magoon, and are of popular interest in Hawaii. Introduce Purseglove's Tropical Crops Monocotyledons and Tropical Crops Dicotyledons as available references and encourage students to read the information regarding the crops they intend to work with. Purseglove's works are in the science reference section of Hamilton Library under the following call numbers:

Ref./SB111/P86 Tropical Crops Dicotyledons; Vol. 1 & 2.
Ref./SB111/P87 Tropical Crops Monocotyledons; Vol. 1 & 2.

Have the students choose the crop for the planting density experiment. Both soybean and corn may be used in two planting density experiments if enough students are interested. (See Suggestions; page 1e.)

2) Discussion -- Instructional Objectives 1 & 2 (½ hour):

Open the discussion by having the students define the treatments for the planting density experiment. Persons in the class who have experience with corn or soybean can suggest a control spacing for the experiment. List the treatments on the board.

Ask the class to comment on the variables which may have to be controlled in the experiment (Worksheet; pages 3 & 4). Illustrate the principles of a randomized block design and show how gradients, time factors, or geographical differences are variables which can be controlled by "blocking."

Sketch a layout of blocks for the planting density experiment and make a randomized assignment of planting density treatments to each block (Worksheet; page 9). The students should record the design before proceeding to the plot area.

B) Presentation (continued)

3) Field Study -- Instructional Objective 3 (2 hours):

Upon entering the Magoon Station, introduce the students to the technician in charge of the facilities and show them the location of the Agronomy 101 tools and supplies.

Begin the field study by examining the uniformity trial and identify "spots" or "gradients" if present. Point out that heterogeneity can be controlled to a certain extent with appropriate experimental designs; "block" designs, for example, can be given as a means of controlling gradient effects. "Edge" or "border" effects may well be exhibited in the uniformity trial; border plants should, therefore, be mentioned as a necessary feature of field experiments.

Remove the uniformity trial and demonstrate how to lay out square corners for field plots. After helping students square the first corner of the planting density experiment, have them square the remaining corners on their own.

The planting density students should then be grouped (two per replicate) and each group asked to independently fertilize and plant each replicate of the planting density experiment. Stress the importance of homogeneity within replicates and warn students against the partial completion of an operation within any one replicate.

The planting density students should be able to complete the layout of their experiment, fertilize their plots, and plant their crop according to design to complete the third Instructional Objective for this session. In the meantime, the instructors can consult with those students who wish to conduct independent plot experiments as they survey the area available to them.

C) Suggestions:

The most important part of the preparation for this session is getting to know the students. Students should be encouraged (if not required) to visit the instructor to discuss their interests at the earliest possible convenience. Perhaps, the time available immediately following the library workshop for AGRONOMY AS A SCIENCE can be used for this purpose. Consultations with students not only facilitate the planning of student projects but also motivate students toward the research responsibilities entailed by their proposed projects. Moreover, consultations help students clarify their own interests and allow them the opportunity to overcome the difficult task of formulating a clear and unambiguous hypothesis.

C) Suggestions (continued)

Planting density is an excellent topic for study as a class project for several reasons. Many growth and yield responses to planting density can be investigated. Scientific literature on the subject, especially with regard to soybean and corn, is both easy to find and instructive. Much of the literature is also a source for ideas for student hypotheses. A requirement that no two student hypotheses be the same insures that a variety of investigations will be conducted as part of the same experiment.

The installation of the planting density experiment early in the semester affords students the opportunity to begin their independent study for Agronomy 101 before actually formulating a hypothesis for their research. However, students who choose to conduct an independent experiment must formulate a hypothesis before carrying out the design and installation procedures.

It is recommended that the planting density experiment be designed such that AT LEAST TWO STUDENTS are involved in the installation and maintenance of each replicate. A randomized block design for the experiment is also recommended in this regard. Two students can easily handle one replicate of a large plot experiment, whereas one student alone cannot be expected to complete the fertilizing, planting, thinning, weeding, etc. of a large replicate. Thus, the number of replicates in the planting density experiment can be determined by the number of students participating. Two planting density experiments, one with soybean and one with corn, may be installed if enough students are interested.

The independent experiments should also be limited in size according to the number of students participating. A completely randomized design may be the most appropriate for these experiments.

As a final suggestion, have students conduct only SINGLE-FACTOR experiments. Multi-factor experiments are considerably more difficult to interpret and are no more instructional in view of the course objectives.

SOIL FERTILITY

OBJECTIVES:

A) Instructional Objectives:

Soil fertility refers to the status of a soil in terms of its available mineral nutrients. An assessment of soil fertility is useful in crop production to determine the fertilizer and amendment practices that will promote high yields and high economic returns on cash crops.

In a combined field and laboratory session, soil sampling and soil testing will be carried out and fertilizer and liming recommendations will be made. The session is designed so that you may assess the soil fertility of an area of your choice. You may, therefore, bring in soil samples of your own for testing. A soil sampling exercise at the Magoon Station is included as an introductory activity so you will also be able to assess the fertility of the plot area for your experiment.

The instructional activities of the combined field and laboratory session are designed so that you may:

1) TAKE representative soil samples from the plot area at the Magoon Station.

2) MEASURE the acidity of the soil samples using either a pH meter, or a colorimetric indicator solution.

3) ANALYZE the soil for four essential mineral nutrients using the rapid chemical method of the Cooperative Extension Service.

4) DETERMINE whether or not lime should be applied as an amendment to the plot area and CALCULATE a specific fertilizer application for the area.

B) Terminal Objective:

If you were given an area of land suitable for crop production, you should be able to have the soil fertility assessed and determine suitable fertilizer and liming requirements for the crop at hand.

WORKSHEET:

A) Soil Sampling:

The soil fertility in a field or a cultivated area is subject to much variability, depending on the nature and history of the land. Soil sampling, therefore, is done in a manner which gives a representative assessment of fertility.

The first step in taking representative samples from an area is to divide the total area into sections, or "sampling areas". To do this, the soil sampler must study such things as the slope, the stoniness, the type of vegetation, the soil color, the past management, etc., since these are indications of fertility variations which may occur from one location to the next. Each sampling area, then, is defined by one or more of these conditions or characteristics, and its fertility is assessed separately.

Each sampling area may be as large as a hectare or more. In fields planted to industrial crops, such as pineapple and sugar cane, large sampling areas are common. However, if there are great variations in the characteristics of the land, as there often are, the area should be divided into smaller sampling areas.

The next step in soil sampling is to take a number of samples from each sampling area. A large number of samples taken from random locations best insures a representative assessment. If only a small number of samples (less than ten) are taken, say because the area is small or because only a rough estimate of fertility is needed, then randomizing the locations of samples may not be necessary. If, however, the fertility of a large or an important sampling area is to be assessed, say a section of a commercial field or an experimental plot area, then it is to the benefit of the sampler to insure a representative assessment by selecting random locations for sampling.

Samples should also be taken in uniform quantities and to uniform depths. An ideal sample is a vertical column of soil taken to the depth of the plow layer or the root zone. Both the plow layer and the root zone vary with the type of crop. Since the plow layer is the cultivated portion of the soil, sampling the full depth of a plow layer affords the most useful assessment of fertility. The root system of a crop, however, is expected to penetrate to depths many times greater than the plow layer. Corn, for example, has a fibrous root system which will penetrate to two meters and beyond in deep, well drained soils during a single growing season. Soil sampling to such depths is not usually advisable, but not altogether unheard of.

B) Soil Testing:

The Agricultural Service Center of the College of Tropical Agriculture routinely measures the acidity (pH) and the available amount of four mineral nutrients (phosphorus, potassium, magnesium, and calcium) as a service to farmers and growers in Hawaii. The rapid chemical method that is used is especially useful for handling a large number of samples while affording meaningful assessments of soil fertility.

The following is an outline of the rapid chemical method that will be used during the laboratory session. You may run tests on as many different samples as you wish, but be sure to test ONE sample from an area for which you wish to make fertilizer and liming recommendations. Follow the outline closely!

1) Determination of SOIL ACIDITY with a pH meter:

a) Fill a 50-ml paper cup with soil.
b) Make a "paste" by mixing in small increments of distilled water.
c) Allow the paste to equillibrate for one hour.
d) Callibrate the pH meter with buffer solution. (Consult instructor!)
e) Measure the pH of the soil paste. (Consult instructor!)

Results:

Sample	
pH	

2) Determination of SOIL ACIDITY with indicator solution:

a) Fill large well of ceramic tray with soil. (Do not compact!)
b) Add indicator in small increments until soil is barely saturated.
c) Let stand for one minute.
d) Tilt tray to allow solution to drain from soil.
e) Compare color of solution with color (pH) chart.

Results:

Sample	
pH	

B) Soil Testing (continued)

3) EXTRACTION of "available" nutrients:

a) Take 4 to 5 cc of soil and place in large test tube.
b) Add 7 ml of 0.3 N HCl solution.
c) Shake for 1 minute.
d) Filter and keep filtrate.

When making the following determinations the comparators will give the level of each nutrient tested in terms of kilograms per hectare (kg/ha) as indicated by either COLOR or TRANSLUCENCE. Record the soil test results for ONE sample in Table 2 on page 11.

4) Determination of PHOSPHORUS:

a) Transfer 0.2 ml filtrate to comparison tube.
b) Add 3 drops ammonium molybdate-sulfuric acid solution.
c) Dilute to mark on comparison tube with distilled water.
d) Add 1 drop $SnCl_2$ solution.
e) Compare immediately with comparator -- the color is unstable.

Results:

Sample	
Available P	

5) Determination of POTASSIUM:

a) Transfer 0.7 ml filtrate to comparison tube.
b) Dilute to mark with sodium acetate solution.
c) Add 2 drops sodium cobaltinitrite solution.
d) Compare translucence (NOT COLOR) with comparator.

Results:

Sample	
Available K	

6) Determination of CALCIUM:

a) Transfer 0.2 ml filtrate to comparison tube.
b) Add 5 drops $Na_2C_2O_4$ solution.
c) Shake for 1 minute.
d) Dilute to mark on comparison tube with distilled water.
e) Compare translucence (NOT COLOR) with comparator.

Results:

Sample	
Available Ca	

B) Soil Testing (continued)

7) Determination of MAGNESIUM:

a) Transfer 0.2 ml filtrate to comparison tube.
b) Add 1 drop titan yellow solution.
c) Dilute to mark on comparison tube with distilled water.
d) Add 12 drops NaOH solution.
e) Compare immediately with comparator BEFORE precipitate forms.

Results:

Sample	
Available Mg	

When you have completed the soil tests, check to see that you have recorded your nutrient determinations for a chosen sample in Table 2 on page 11. Use these results to complete the fertilizer recommendation exercises on pages 11 and 12.

C) Determining Liming Requirements:

A measurement of soil acidity is, perhaps, the most useful test that can be made to assess the availability of plant nutrients in the soil. Soil acidity is measured in pH units. The units refer to the concentration of hydrogen (acid) ions which go into solution when the soil is wet. The hydrogen ion concentration has an important effect on the solubility, and therefore, the availability of mineral nutrients to plant roots.

The pH scale is divided into fourteen units. By definition, "acid soils" are those soils which have pH levels less than pH = 7.0. Soils which have pH levels greater than 7.0 are called "alkaline soils". The reference value, pH = 7.0, is at the exact center of the pH scale. Soils with a pH of 7.0 are called "neutral soils". The pH levels of most agricultural soils are between 4.0 ("strongly acid") and 8.0 ("slightly alkaline").

The rationale behind measuring acidity in terms of pH units is a mathematical one based on the dissociation properties of water. Water dissociates into hydrogen (H^+) and hydroxyl (OH^-) ions. The dissociation is symbolically written

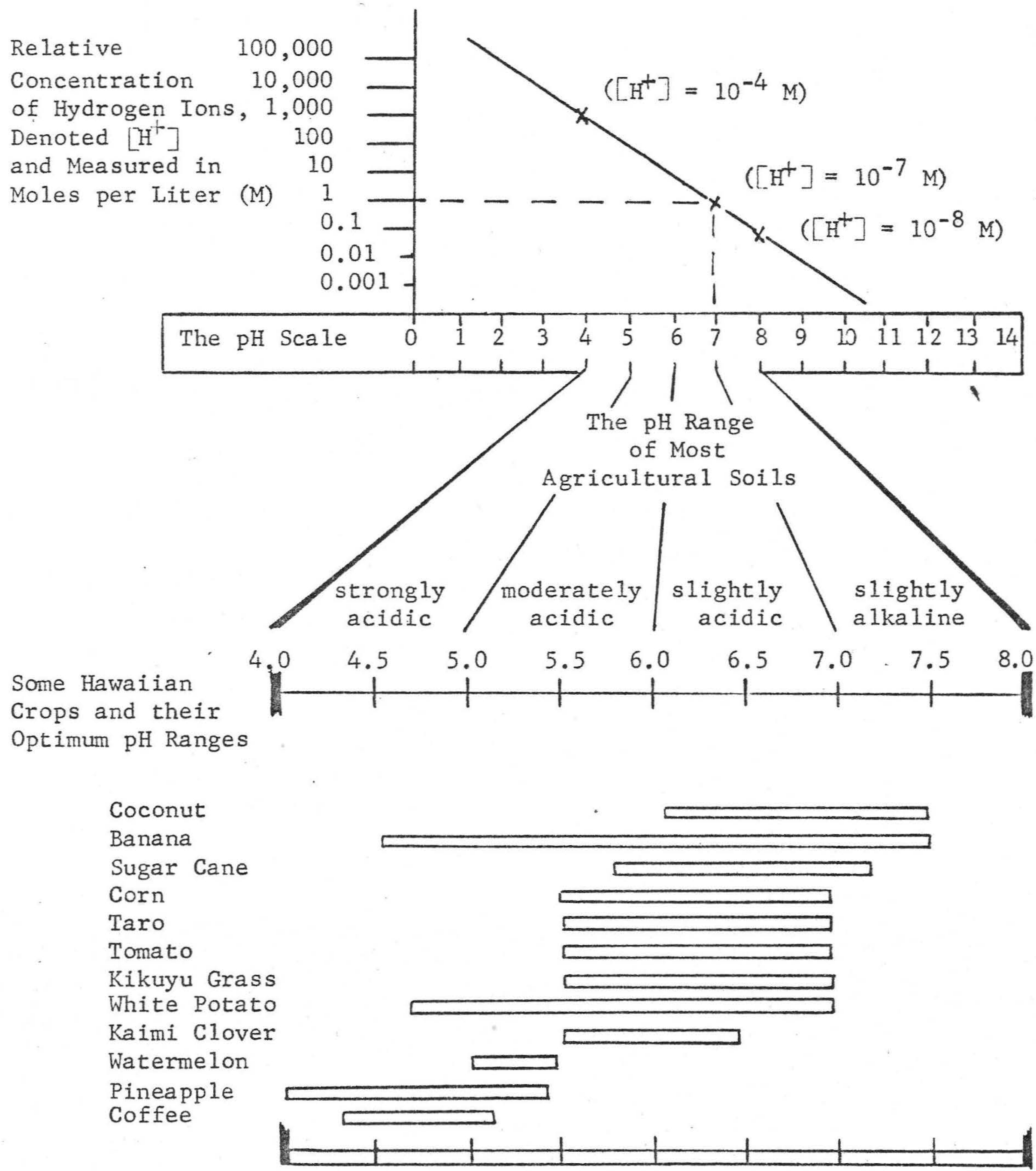
$$H_2O \rightleftharpoons H^+ + OH^-.$$

For each unit difference in the pH of a solution, there is a ten-fold difference in the number of hydrogen ions in the solution. Thus, at pH = 7.0 there are ten times more hydrogen ions in a solution than there are in the same solution at pH = 8.0. The magnitude of differences in the concentration of hydrogen ions across the pH scale is indicated in Figure 1 on page 6.

Optimum pH ranges for a number of crop plants grown in Hawaii are also shown in the chart on page 6. Optimum pH ranges are experimentally determined and depend to some extent on soil and climatic conditions; they are not solely determined by the crop. This, in fact, explains why the optimum pH range for many crops is between 6.0 and 7.0 in temperate regions and between 5.5 and 6.5 in tropical regions. Nonetheless, for a given environment, each crop has a pH range for which it is suited, and each is tolerant of only a certain amount of acidity or alkalinity.

Figure 1

pH; A Measure of Soil Acidity



Adapted from Brady (1974) and McCall (1969)

C) Determining Liming Requirements (continued)

A soil amendment is a substance which is used to alter the properties of a soil in such a way that plant growth is enhanced. Liming materials such as ground coral and ground limestone, which are largely calcium carbonate ($CaCO_3$) or a mixture of calcium carbonate and magnesium carbonate ($MgCO_3$), are two soil amendments that are commonly used to raise the pH (i.e.; to lessen the acidity) of soils. This is often necessary with highly weathered soils and with soils that have received large amounts of acid forming fertilizers.

Calcium carbonate and magnesium carbonate each contain an essential mineral nutrient. For this reason they are sometimes also used as fertilizers.

Questions:

1) In the plot area at the Magoon Experiment Station, is liming a necessary or recommended amendment practice for your experiment? Explain!

2) Can you think of a method which could be used to determine the liming needs of a particular soil which is too acidic for a particular crop?

D) Determining Fertilizer Requirements:

Chemical elements which are absorbed by plant roots in water soluble forms and are utilized by plants for growth and development are called mineral nutrients. There are at least thirteen essential mineral nutrients. These are listed in Table 1 on page 10 along with the forms in which these nutrients are available to plants. The approximate amount of each nutrient that is removed from the soil by a high yielding corn crop during a single growing season is also listed.

The first six mineral nutrients listed in Table 1 are required in the greatest amounts by all crop plants. In crop production, the most useful soil tests provide a measure of the availability of these six nutrients, often referred to as macronutrients. The last seven mineral nutrients listed in the table are used in such small amounts by plants that they are commonly called micronutrients.

It is important to realize that soil tests are useful primarily because they assess the availability of nutrients rather than their total supply. For this reason, many nutrients, including nitrogen, are not always assessed in a soil test. The status of available nitrogen, for instance, is so variable, depending on the moisture, texture, temperature and organic matter of the soil, that its assessment is not always representative of the nitrogen which is truly available to a crop. Although the micronutrient supply tends to be more stable than does nitrogen, available micronutrients usually cannot be easily and reliably measured by soil testing.

Different crops have different mineral nutrient requirements, just as they have different optimum pH ranges. Knowing the mineral nutrient requirements for a given crop, and knowing the mineral nutrient status of a soil, one can determine how much nutrient should be added in the form of fertilizer. In Table 1, the thirteen nutrient requirements listed pertain to corn. Nutrient requirement tables for other crop plants (often supplied by fertilizer industries) are valuable references for growers.

During the laboratory session, a nutrient requirement chart for several crops will be available for you to use when making fertilizer recommendations.

Table 1

Essential Mineral Nutrient Requirements
for the Production of 8,000 Kilograms of Mature Corn Ears
on One Hectare of Farm Land

Macronutrient	Symbol	Available Forms	Approximate Crop Requirement
Nitrogen	N	NO_3^-, NH_4^+	240 kilograms/ha
Potassium	K	K^+	200
Calcium	Ca	Ca^{++}	50
Magnesium	Mg	Mg^{++}	50
Phosphorus	P	$H_2PO_4^-$, $HPO_4^=$	40
Sulfur	S	$SO_4^=$	30
Micronutrient			
Chlorine	Cl	Cl^-	3
Iron	Fe	Fe^{+++}, Fe^{++}	3
Manganese	Mn	Mn^{++}	1.5
Boron	B	BO_3^{-3}, $B_4O_7^=$	0.5
Zinc	Zn	Zn^{++}	0.5
Copper	Cu	Cu^{++}, Cu^+	0.2
Molybdenum	Mo	$MoO_4^=$	0.003

Adapted from Salisbury & Ross (1969) and the Plant Food Utilization Tables of the Potash Institute of North America.

D) Determining Fertilizer Requirements (continued)

A soil fertilizer is any material which is added to a soil to supply additional mineral nutrients. Fertilizers can be either natural or synthetic in origin, and they may contain both organic and inorganic materials.

Table 2 below can be completed as an initial step in making a fertilizer recommendation. The table is set up so that soil test results can be compared with the mineral nutrient requirements of a given crop.

Table 2

Soil Test Results and Mineral Nutrient Requirements

Nutrient	Soil Test Results (from comparator results; pages 4 & 5)					Mineral Nutrient Requirement in kg/ha for ______ * (crop to be grown)
	Status check appropriate boxes				Available Amount in kg/ha	
	low	mod.	high	exc.		

*Nutrient requirements can be obtained from Table 1 (page 9) or from other appropriate plant nutrient utilization tables.

Question:

For each of the nutrients in Table 2, which of the following criteria might be used to govern its addition to the soil?

Criteria	Nutrient
1) No nutrient needed. . . .	
2) Maintenance amounts needed . .	
3) More than maintenance amounts needed to replenish soil. . .	

D) Determining Fertilizer Requirements (continued)

The following table can be completed to illustrate how fertilizer recommendations are made for a given field or plot area. First, criteria for the addition of nutrients to the soil (page 11) are used to determine recommended rates of nutrient application (in kg/ha). Then, knowing the percent nutrient content of each fertilizer to be used, the amount of fertilizer needed to meet each recommendation can be calculated. Finally, the recommended fertilizer rates (in kg/ha) must be converted to the dimensions of the land area at hand. To make this conversion, you must know the area of the plot or field for which the recommendations are to be made.

Table 3

Mineral Nutrient and Fertilizer Recommendations

Area of plot or field to be fertilized: ____________ ha.

Crop to be grown: ______________

Nutrient	Recommended nutrient application (kg/ha)	Fertilizer type; Soluble component; % Nutrient content	Recommended fertilizer application (kg/ha)	Recommended fertilizer application (kg/______)
N		Urea $CO(NH_2)$ 46% N		
K		Potash KCl 50% K		
Ca		Calcium Sulfate $CaSO_4$ 30% Ca		
Mg		Epsom Salt $MgSO_4 \cdot 7H_2O$ 10% Mg		
P		Treble Superphosphate $Ca(H_2PO_4)_2$ 10% P		

REFERENCES AND SELECTED READINGS:

Brady, N. C. (1974). The Nature and Properties of Soils. MacMillan. 639 p. Chapter 14; "Soil Reaction: Acidity and Alkalinity." Chapter 19; "Fertilizers and Fertilizer Management."

McCall, W. W. (1969). Learn to Interpret Your Soil Test Results. Cooperative Service Circular 432. University of Hawaii. 11 p.

___________. (1972). Take Good Soil Samples for Fertility Recommendations. Cooperative Service Circular 428. University of Hawaii. 10 p.

___________ and R. T. Watanabe. (1974). Soil Reaction (pH); General Home Garden Series #8. A Cooperative Extension Publication. University of Hawaii. 2 p.

Potash Institute of North America. (1972). Plant Food Utilization Tables. Available as an information circular published by the Institute.

Salisbury, F. B. and C. Ross. (1969). Plant Physiology. Wadsworth. 747 p. Chapter 10; "Mineral Nutrition of Plants."

PHYSICAL CHARACTERISTICS OF SOILS

OBJECTIVES:

A) Instructional Objectives:

A soil is composed of mineral and organic materials whose primary particles are clustered into aggregates of varying size, shape and stability. The physical characteristics of soils are largely determined by the size of their constituent particles and by the nature of the aggregates formed by these particles.

This session is a combined classroom and field study session wherein a few important physical characteristics of soils will be investigated. In particular, the alteration of certain physical characteristics will be considered in relation to the management of soils for crop production.

The instructional activities for this session are such that you will be able to:

1) IDENTIFY, as would be done in the field, both the textural class and the structural type of three soils (a sand, a loam, and a clay) and DISCUSS the limitations to determining texture in the field.

2) CALCULATE the bulk densities of known volumes of oven-dry sand and oven-dry clay soil and EXPLAIN the difference.

3) PLOT root growth as a function of bulk density and INTERPRET the results in terms of management concerns.

4) COMPARE the physical characteristics of a tilled, a spaded and an undisturbed plot in terms of

   a) soil structure.
   b) permeability.

B) Terminal Objective:

If you were given an area of land suitable for crop production, you should be able to describe the soil in terms of its physical characteristics and suggest how the soil structure can be improved or maintained to enhance crop growth.

WORKSHEET:

A) Soil Texture:

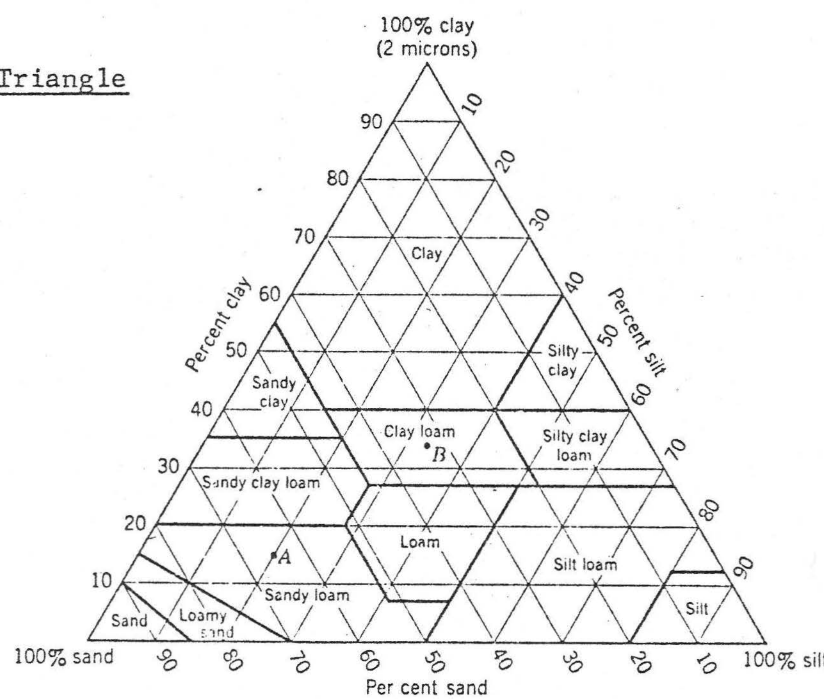
The size of primary soil particles varies tremendously. By definition, the smallest of all soil particles, having diameters less than 0.002 mm, belong to the clay fraction of the soil. Silt particles have diameters ranging from 0.002 to 0.05 mm. Sand particles have diameters between 0.05 and 2 mm.

The relative amounts of sand, silt and clay particles contained in a soil determine what is known as the textural class of the soil. A soil texture triangle (Figure 1) is used to designate the composition of each textural class in terms of the percentages of sand, silt and clay. Twelve textural classes have been defined and are shown in Figure 1.

Three soils will be provided at one of the classroom stations. The approximate particle size composition of each sample will be given by the instructor. Feel each of the soils for its characteristic texture. Use water in small quantities to wet the soil and compare the sticky or cohesive nature of the samples. "Stickiness" is largely due to the clay fraction of a soil. Ask the instructor to show you how to test for a clay soil by rolling moist soil between the thumb and fingers to form "ribbons." (Clay soils form good ribbons.) Next, use the soil texture triangle to identify the textural class of each sample.

Figure 1

Soil Texture Triangle

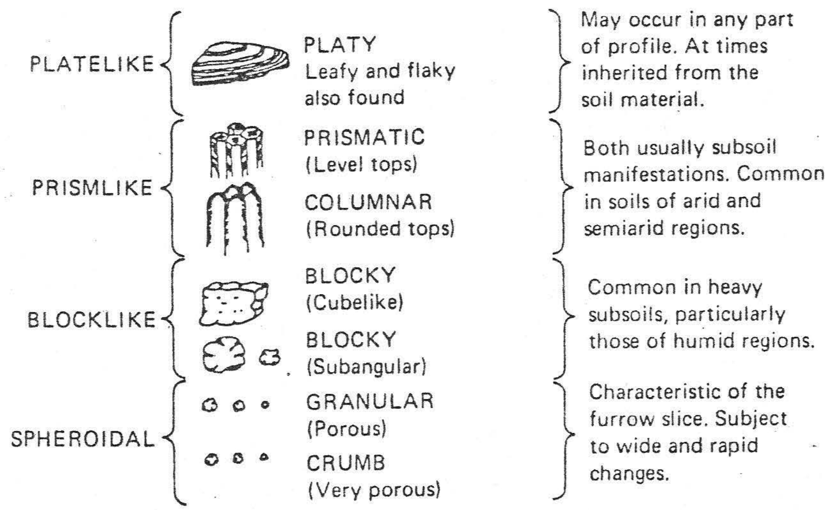


B) Soil Structure:

Soil structure refers to the size, shape, arrangement and stability of aggregates of primary soil particles. Soil aggregates are classified according to the structural types shown in Figure 2.

Figure 2

Classification of Structural Types



Photocopy from Brady, N. C. (1974) page 56.

Examine the aggregates of the three soils provided by the instructor and identify the structural types present.

B) Soil Structure (continued)

Questions:

1) Why is a stable granular structure prized by farmers?

2) How does organic matter contribute to the formation of a stable, granular structure in clay (fine textured) soils?

3) Is the "looseness" of a soil in any way influenced by soil structure? Explain!

4) What are the particle size distributions of the soils represented by points "A" and "B" in Figure 1 on page 2?

C) Bulk Density and Porosity:

Bulk density refers to the total mass of particles (solid only) contained in a unit volume of oven dry soil. The volume includes the entire space occupied by both particles and pores. The fraction of the total volume which is occupied by pores is called the porosity.

Complete Table 1 below and compare the bulk densities of 500 grams of oven dry clay soil and 500 grams of oven dry sand. The clay soil and the sand will be weighed out and put in beakers for this exercise.

Table 1

Determination of Bulk Density for Clay Soil and Sand

	CLAY SOIL	SAND
Mass of Dry Soil (grams)		
Volume of Dry Soil (cc)		
Bulk Density (grams/cc)		

Explain the difference in bulk density in terms of porosity!

D) Compaction:

A loose, porous soil is desirable for normal root growth. Compaction reduces porosity. It is sometimes desirable to know how much compaction can be tolerated by a soil, especially in cases where heavy equipment is used in conjunction with planting, pesticide application, harvesting, etc.

In the following activity, you are asked to collect and analyze the results of a demonstration in which corn will be germinated and grown in soil that is compacted to a range of bulk densities. Use Table 2, below, to record the results of this demonstration along with relevant observations.

Each student or group of students will make growth measurements for a single treatment and will report the measurements on the blackboard for others to record.

Table 2

Results of Soil Compaction Experiment

Bulk Density (gm/cc)	Mass of Tops (grams)	Mass of Roots (grams)	Ratio Tops:Roots	Observations
0.7				
0.9				
1.1				
1.3				
1.5				

Does the data indicate a trend in the tops:roots ratio with increased compaction? Why do you think there is or is not a trend?

D) Compaction (continued)

Two physical properties -- bulk density and porosity -- can be used as indexes of compaction. Both are related by the equation

$$\text{Porosity} = 1 - \frac{\text{bulk density}}{\text{particle density}},$$

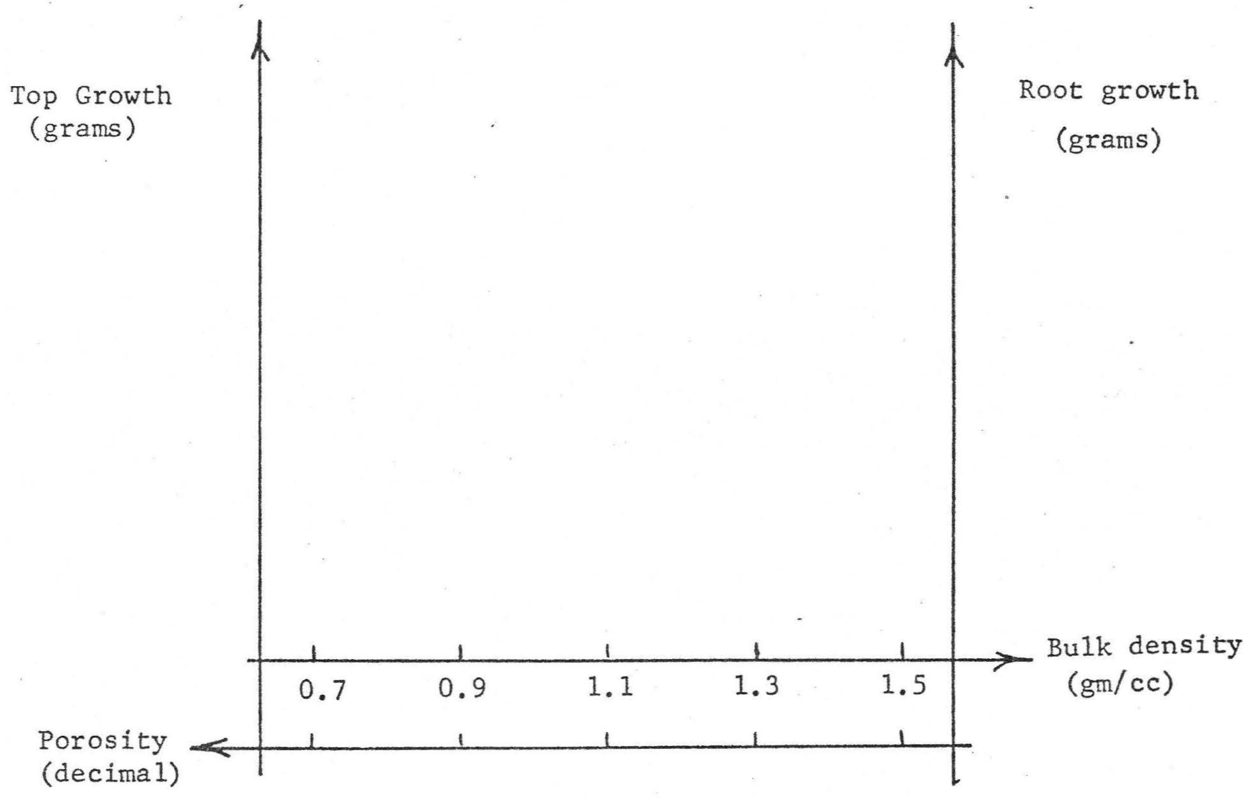
where particle density refers to the average density of each of the primary soil particles. The density of particles in a typical Hawaiian soil is about 2.9 times that of water or 2.9 gm/cc.

Use the data in Table 2 to plot the growth of both tops and roots as a function of compaction. Use the grid provided below (Figure 3) to make your plot. On the independent axis designate the porosity which corresponds to each of the designated bulk densities.

Figure 3

Growth Response to Compaction

(from data in Table 2)



D) Compaction (continued)

Questions:

1) Which of the curves in Figure 3 indicate(s):

a) a negative response?
b) no response?
c) a positive response?

2) Are either or both of the response curves linear? If not, describe!

3) Do either of the response curves suggest that soils under cultivation can tolerate a certain degree of compaction before crop growth is seriously affected?

4) Can you offer TWO reasons for the fact that root growth is restricted in heavily compacted soils?

E) Tillage:

Tillage, as opposed to compaction, "loosens" soils and serves to increase or maintain soil porosity. Tillage, or compaction, also affects the permeability of a soil to both air and water. Permeability is an important concern where irrigation or rain waters are susceptible to runoff. Permeability is also important where rainwater may accumulate as standing water and thus become a threat to crop growth.

As a final exercise, collect observations from a tillage demonstration which will be prepared in the field for this session. The demonstration consists of three plots; one left undisturbed, one spaded with a shovel, and one tilled intensively with a tractor. Ten centimeters of water will be applied to each of the plots and infiltration times will be recorded and made available to you by the instructor. Record these times in Table 3, below. Also record your observations of soil structure for each of the plots. Can you explain the differences in permeability (as measured by infiltration) in terms of soil structure?

Table 3

Infiltration Times (t_x) and Soil Structure Observations for Three Plots

		Undisturbed	Spaded	Tilled
Infiltration time (t_x) in minutes	$t_{0.5}$			
	$t_{0.6}$			
	$t_{0.7}$			
	$t_{0.8}$			
	$t_{0.9}$			
	$t_{1.0}$			
Observations				

REFERENCES AND SELECTED READINGS:

Brady, N. C. (1974). The Nature and Properties of Soils. Macmillan. 639 p. Chapter 3; "Some Important Physical Properties of Mineral Soils."

Foth, H. D. and L. M. Turk. (1972). Fundamentals of Soil Science. Wiley. 454 p. Chapter 3; "Physical Properties of Soils."

Hart, J. M. and D. T. Lewis. (1973). Instruction in soil texture determination -- A teaching aid for beginning students. Journal of Agronomic Education, 2:18-20.

Richman, R. W., J. Letey and L. H. Stolzy. (1965). Soil compaction effects on oxygen diffusion rates and plant growth. California Agriculture, 19(3):4-6.

INSTRUCTOR'S NOTES:

A) Materials and Preparation:

1) Soil Compaction Demonstration:

Three to four weeks in advance of the session, five kilograms (dry wt. basis) of soil from the Magoon plot area should be screened through a 2 mm sieve and prepared as follows:

a) Determine the gravimetric water content.

b) Wet soil to 30% water content and mix to achieve homogeneity.

c) In each of five 900 cc tin cans (punched with drainage holes) put the following amounts of wet soil and compact as needed to 800 cc:

i) 720 grams of wet soil (little or no compaction needed).
ii) 930 grams of wet soil.
iii) 1140 grams of wet soil.
iv) 1350 grams of wet soil.
v) 1560 grams of wet soil (heavy compaction needed).

The bulk densities listed in Table 2 (page 6) are thus established.

d) On the surface of the soil in each can place 3 or 4 seeds of a chosen variety. Either soybean or corn can be used. Two species can be used if two demonstrations are desired, in which case two sets of compacted soil need to be prepared.

e) Fill the cans with wet soil. The seeds are thus planted and should be grown for three weeks before growth data is collected by the class. Watering should be frequent, especially during the third week when transpiration is rapid.

A) Materials and Preparation (continued)

2) Soil Tillage Demonstration:

This demonstration should be prepared five to seven days prior to the session. Three one square meter ($1\ m^2$) plots are needed. The plots should be located in an area which is free of stones and boulders and has a soil structure somewhat representative of an untilled or undisturbed condition. Clear the plots of vegetation and remove the surface soil to a depth of 10 cm. Each plot is thus clearly identified by the $1\ m^2$ by 10 cm space above it.

Leave one plot undisturbed. Spade one plot to a depth of 30 to 40 cm and leave large clods unbroken. Till one plot intensively to a depth of 30 to 40 cm with a tractor to break apart all clods. Install four tensiometers (vacuum guage type are best) per plot; two at 15 cm depth (measured from soil surface to tip of porous cup) and two at 30 cm depth. Apply 10 cm (100 liters) of water to each of the plots. Record the infiltration time in minutes for 5, 6, 7, 8, 9, and 10 cm of water. This is an important part of the preparation of this demonstration. Infiltration times can be recorded by the instructor in a table such as the one below. Infiltration times will then be given to the students during the session to record in Table 3 on page 9. (See Presentation; page 1d.)

Infiltration Times (t_x) for Three Plots

Amount of Infiltration	t_x	Plot		
		Undisturbed	Spaded	Tilled
5cm	$t_{0.5}$			
6	$t_{0.6}$			
7	$t_{0.7}$			
8	$t_{0.8}$			
9	$t_{0.9}$			
10	$t_{1.0}$			

Shelter the plots from rain-water, but leave plots exposed to the air to facilitate the development of soil moisture tensions in the surface soil prior to class. A plastic tent is a suggested shelter.

A) Materials and Preparation (continued)

3) Instructional Materials:

The materials which need to be collected for this session are:

a) Soils of various textural classes labeled as to their approximate particle size distribution.

b) Soil samples representative of several structural types with accompanying descriptions of where these structural types are commonly found.

c) Water in squirt bottles for determining texture by feel.

d) One 600 ml beaker and one 400 ml beaker, each containing 500 grams (dry weight basis) of clay soil and sand, respectively. The beakers should be clearly labeled to identify their contents by:

i) volume.
ii) dry weight.

e) Compaction demonstration with bulk densities clearly identified.

f) Containers for discarding soil from compaction demonstration.

g) Wash basins for washing plant roots.

h) Paper towels for drying washed material.

i) One or two balances for weighing roots and tops.

j) Nine aluminum rings of known volume for taking soil (core) samples.

k) Nine moisture cans (with lids) for collecting, labeling, and drying core samples.

l) Several spades and hand towels for taking core samples.

m) At least one sharp knife for leveling surfaces of each core sample.

B) Presentation (A combined classroom and field study session):

1) Texture, Structure and Bulk Density -- Instructional Objectives 1 & 2 (1 hour):

Have the students begin the session by making soil texture and soil structure observations. Students will have to be helped on an individual or group basis, especially when feeling for clay and when reading the texture triangle. Show students how to test for clay by forming "ribbons" with moistened samples between the thumb and fingers.

AFTER students have completed their investigations, discuss some of the management concerns for each of the physical properties introduced.

2) Effect of Compaction -- Instructional Objective 3 (1 hour):

Briefly describe the preparation of the compaction demonstration. Before collecting growth measurements, remove plants from cans and record observable features of both roots and tops (eg.; root and stem thickness, development of adventitious roots, height, etc.). The students can then divide the five samples among themselves, separate the roots from the tops at the first adventitious or secondary root, wash the roots, remove excess moisture, weigh tops and roots separately, and report their measurements on the board for others to record.

Use the questions on page 8 as a base for a discussion of the results of this demonstration.

3) Effect of Tillage -- Instructional Objective 4 (1 hour):

This activity should be carried out in its entirety at the demonstration site. Begin by briefly explaining the preparation of this demonstration and give students the infiltration data for each of the plots. Ask the students to look for physical characteristics which may explain the infiltration differences (eg.; evidence of ponding, stable or unbroken clods, etc.).

Have students take tensiometer readings and have them report the tensions in Table 3 on page 5 of the "Worksheet" for the session entitled "SOIL WATER". The data will be examined during that session and need not be discussed at this time.

B) Presentation (continued)

3) Effect of Tillage -- Instructional Objective 4 (1 hour) (continued):

Show students how to take undisturbed core samples. Have students take three samples from 15 cm below the surface in each plot. Soil cores should be put in moisture cans. Make sure the moisture cans are labeled as the samples are collected.

While students are taking core samples, continue to compare the physical characteristics among the plots. The instructor may wish to discuss the principles of the genesis and stability of granules. Evidence of aggregate stability or instability could be shown to the students. The following sections in Brady (1974) might be a useful reference to the instructor in preparing for such a discussion:

3:10 -- Aggregation and Its Promotion in Arable Soils.
3:11 -- Structural Management of Soils.
3:12 -- Soil Consistence.
3:13 -- Tilth and Tillage.

Note: The core samples (wet soil + ring + moisture can) must be weighed and put in the drying oven by the instructor as part of the preparation for the SOIL WATER session.

C) Suggestions:

An introductory discussion is NOT recommended for this session. Rather, the session should begin with the texture, structure and bulk density activities. The instructor should guide the students on an individual or small group basis with the intention of leading them TOWARD a discussion of what texture, structure and bulk density mean to a farmer or to an agronomist.

It may be wise to use two plant species for the soil compaction demonstration; in which case two sets of compacted soil should be prepared. Corn seedlings, having a fibrous root system, and soybean seedlings, having a taproot system, may afford some interesting and worthwhile comparisons. A large class can be divided to collect data from both sets of plants independently. The final response curves can be plotted on the board, side by side, to facilitate final comparisons.

C) Suggestions (continued):

The interpretation of seedling response to compaction should, indeed, go beyond the mere conclusion that roots grow poorly in compacted soils. A student's efforts to interpret the results of his response curves should be an exercise in extracting from a graph as much useful information as is possible. The questions on page 8 are intended to aid the student with his interpretation.

Finally, any discussion of the tillage demonstration, should be conducted AT THE ACTUAL SITE OF THE DEMONSTRATION. The concepts to be developed in conjuction with this demonstration need no classroom introduction apart from the texture, structure and bulk-density activities which open the session.

SOIL WATER

OBJECTIVES:

A) Instructional Objectives:

Crop plants depend on the ability of the soil to retain large quantities of water. The water retention characteristics of a soil are determined by both the physical characteristics of the soil and the amount of water present.

This session has been designed around a few demonstrations which introduce the principles of soil water retention and illustrate the effect of retention forces on the removal of soil water by plants. You will be involved in the data collection from the demonstrations and will be required to interpret the data and draw appropriate conclusions. Use the information you obtain from the demonstrations to:

1) EXPLAIN the effects of tillage on soil water retention.

2) COMPARE the relative ease of water removal from soils of different texture and
DEFINE, in your own words, "available water" as it pertains to crop growth.

3) PLOT a soil moisture characteristics curve and IDENTIFY the following parts of the curve:

    a) saturation.
    b) field capacity.
    c) wilting range.
    d) available water range.

B) Terminal Objective:

If you were given an area of land suitable for crop production, you should be able to evaluate the water holding capacity of the soil and suggest a feasible method of monitoring the soil water status throughout the life cycle of the crop grown.

WORKSHEET:

A) Soil Water Retention:

Just as tillage operations affect the permeability of a soil to irrigation or rain water, so do they affect the water retention characteristics of a soil. This activity is a continuation of the tillage study introduced in the preceding session (PHYSICAL CHARACTERISTICS OF SOILS, page 9) and deals specifically with the physical characteristics which are closely related to soil water retention.

Soil (core) samples will be taken in preparation for this activity. The instructor will demonstrate the coring procedure which is commonly used to study soil water relations. You will be asked to assist with the sampling and will be provided with metal rings for the purpose. The soil cores will be put in moisture cans, weighed, oven dried, and then weighed again to determine:

1) $$\text{volumetric water content} = \frac{\text{volume of core occupied by water}}{\text{volume of core}}.$$

2) $$\text{bulk density} = \frac{\text{mass of dry soil in core}}{\text{volume of core}}.$$

3) $$\text{porosity} = 1 - \frac{\text{bulk density}}{\text{particle density}}.$$

The measurements and calculations obtained in this activity should be recorded in Table 1 on page 3. A summary and interpretation of the results can be made on page 4.

INSTRUCTOR'S NOTES:

A) Materials and Preparation:

If a resource person from the Cooperative Extension Service is available to discuss the use of the rapid chemical method, then he should be contacted well in advance of the session.

The following are the instructional materials which should be gathered or prepared for this session:

1) One-gallon plastic bags for collecting soil samples (20).

2) Permanent felt markers for labeling bagged samples (several).

3) Spades and shovels for sampling (several).

4) pH meter with electrodes.

5) Buffer solutions; pH = 4.0 and pH = 7.0.

6) 50 ml paper cups for preparing soil pastes (many).

7) Wooden spatulas or glass rods for preparing soil pastes (many).

8) Wash bottles of distilled water (several).

9) Soil pH indicator solutions with ceramic trays (several). LaMotte Chemical, Duplex Indicator for Soils, code 2221-F gives good results and is easy to use.

10) Dish soap.

11) Test tube brushes.

12) Kimwipes.

13) Whatman 5 or 10 cm ashless No. 42 filter paper (1 box per lab bench).

14) 10 ml graduated cylinders (several per lab bench).

15) Tables of crop nutrient requirements. (The "Plant Food Utilization Tables" published by the Potash Institute of North America can be used. Students appreciate extra copies as they can be used again in the future.)

A) Materials and Preparation (continued)

16) Colorimetric comparators;* two types:

a) With color plate for phosphorus and potassium tests (several).

b) With color plate for calcium and magnesium tests (several).

17) Student soil test kits (one per student) consisting of:

a) 25 ml test tube with 3.5 and 5 ml graduations.
b) No. 2 rubber stopper.
c) Filtering tube, with funnel-shaped top.*
d) Dropper pipette with 0.2 and 0.7 ml graduations.
e) Comparison tubes with 4.0 ml graduation.*
f) Test tube rack.

18) Reagents for rapid chemical method (One set per lab bench). The preparation of the reagents is described below.** Note: Some of the reagents deteriorate quickly. It is wise to prepare or obtain the complete set within a few hours before the laboratory session and store them in the refrigerator.

a) Hydrochloric acid, 0.3 N: Dilute 50 ml concentrated HCl to 2 liters of solution.

b) Stannous chloride: This solution must be fresh. Put or retain some tin granules in a dropping bottle. Decant old solution, as applicable. Wash tin several times with distilled water. Add 5 to 10 ml concentrated HCl. Let reaction take place for 2 to 4 minutes. Dilute 5 to 10 times with distilled water. Keep in refrigerator.

c) Sodium acetate, 2%: Dissolve 25 grams NaAc in 1 liter of 65 to 70% methyl alcohol.

d) Sodium cobaltinitrite: Dissolve 30 grams $Na_3Co(NO_2)_6$ in 100 ml distilled water.

*Materials obtainable from Hellige Inc., 877 Stewart Ave., Garden City, New York, 11534. Materials listed in catalogue (c 1965) under "Hellige-Truog Combination Soil Tester."

**These descriptions were kindly provided by Cooperative Extension Personnel.

A) Materials and Preparation (continued)

e) Sodium oxalate, 3%: Dissolve 30 grams $Na_2C_2O_4$ in 1 liter distilled water. Adjust pH to 8.9 with sodium hydroxide or oxalic acid.

f) Titan yellow: Dissolve 0.15 grams titan yellow in 100 ml 50% methyl alcohol. Store in amber bottle or use immediately.

g) Sodium hydroxide, 14.5%: Dissolve 14.5 grams NaOH in 100 ml distilled water. Store in tightly stoppered bottle.

h) Ammonium molybdate -- sulfuric acid solution: Dissolve 16.8 grams $(NH_4)_6 Mo_7 O_{24} \cdot 4H_2O$ in 100 ml distilled water. Dilute 137.5 ml concentrated H_2SO_4 to 400 ml with distilled water. Cool to room temperature. Mix both ammonium molybdate and sulfuric acid solutions with stirring. Cool to room temperature. Dilute to make 1 liter of solution.

B) Presentation (A combined field and laboratory session):

1) Soil Sampling -- Instructional Objective 1 (1 hour):

The class should meet, weather permitting, at the Magoon Station where they can participate in soil sampling. Point out the difference between representative sampling and randomized sampling. Take samples from two depths from systematically chosen locations within the experimental plot area. Try to include samples from low fertility spots.

2) Soil Testing -- Instructional Objectives 2 & 3 (1 to 2 hours):

Bring samples from the Magoon Station to the laboratory. Divide the samples among the students and have them run both pH tests and chemical tests (pages 3, 4 and 5). A summary of results should be tabulated on the blackboard by students as they complete the tests. The table might be drawn like the one below.

R.C.M Results

Plot area, Magoon Station, __________
(location) (date)

Sample		pH	avail. P	avail. K	avail. Mg	avail. Ca
	surface					
	subsurface					
	surface					
	subsurface					

Allow students to test as many soils as they are interested in. The results of their tests can be recorded on pages 3, 4 and 5.

3) Determining Soil Requirements -- Instructional Objective 4:

Students should use the test results for ONE sample to make fertilizer and liming recommendations. Pages 11 and 12 are provided for this purpose. Table 3 on page 12 is designed so that it can be completed as soon as the student has obtained both test results and the mineral nutrient requirements of the crop he is interested in.

C) Suggestions:

If weather or other factors do not permit a class meeting at the Magoon Station, samples from the plot area should still be available for testing. Several samples should, therefore, be taken well in advance of the session. A general introduction to the principles and procedures used in soil sampling can be given in the classroom in lieu of the field activity. Encourage students to bring in their own samples for testing during this session!

Resource persons can be of valuable assistance to both the planning and the delivery of this session. It is recommended that a person from the C.E.S. be on hand for a short time during the session to discuss the principles of determining fertilizer requirements by chemical techniques.

Since the rapid chemical method takes some students considerably more time than it does others, formal discussion during the period should be minimal. Helping students individually or in small groups is quite effective and a detailed review of the method is not necessary.

Table 1

Data from Tillage Demonstration

Treatment	Undisturbed			Spaded			Tilled		
Sample number									
Wet soil + ring + moisture can (mass in grams)									
Dry soil + ring + moisture can (mass in grams)									
Water lost (mass in grams = volume in cc)									
Core volume (cc)									
Volumetric water content (decimal)									
Can + ring (mass in grams)									
Dry soil (mass in grams)									
Bulk density (grams/cc)									
Particle density (grams/cc)									
Porosity (decimal)									

A) Soil Water Retention (continued)

Three things -- the volumetric water content, the bulk density, and the porosity -- are important in this demonstration. Averages of the treatment values can be computed and recorded in Table 2, below.

Table 2

Results of Tillage Demonstration

(from original data in Table 1)

Treatment	Undisturbed	Spaded	Tilled
Volumetric water content (decimal or percent)			
Bulk density (grams/cc)			
Porosity (decimal or percent)			

Interpret the results of this demonstration in terms of water retention characteristics. Include the influence of the physical characteristics of the soil in your discussion. You may wish to make a graph to illustrate the results.

A) Soil Water Retention (continued)

Tensiometers were installed in the tillage plots to measure the soil moisture tensions at depths of 15 and 30 cm. The concept of tension is considered in a later demonstration, but is introduced here as a relative measure of the dryness of the soil. In Table 3, below, record the tensiometer readings at the time of core sampling.

Table 3

Tensiometer Data from Tillage Demonstration

(Record data in bars*)

Treatment	Undisturbed		Spaded		Tilled	
15 cm below surface						
30 cm below surface						

*Note: One bar is approximately equal to one atmosphere pressure.

Questions:

1) Do the tensiometer readings at 15 cm support the data obtained in Table 2? Explain!

2) Can your interpretation of the results at 15 cm be extended to include an interpretation of the results at 30 cm? Elaborate!

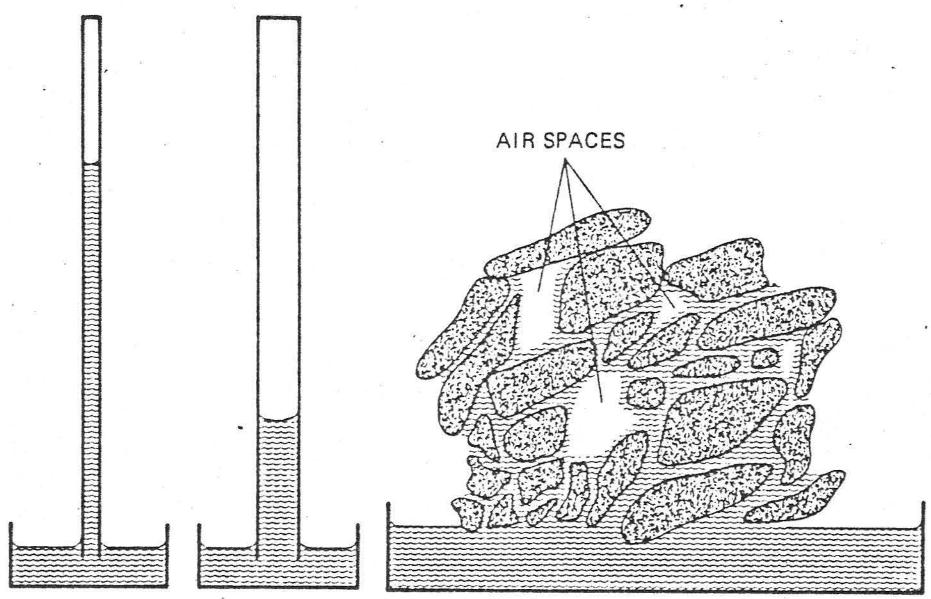
B) Capillarity:

Water which is retained within a soil against the force of gravity is held in the soil pores by capillary forces. The principle of capillarity is illustrated by the upward movement of water in glass tubes of different size. Water will rise to a greater height above a free water surface in tubes of narrower dimensions. Figure 1, below, illustrates how this principle applies to the upward movement of water in soils.

The principle of capillarity explains why soils with a predominance of large pores drain more easily and retain LESS water than do soils with a predominance of smaller pores. In fact, the principle of capillarity, coupled with porosity differences, explains why clay soils are able to retain MORE water per unit volume than sandy soils. This concept is developed further in the following demonstration.

Figure 1

Capillarity and Soil Water Retention



Photocopy from: Brady, N. C. (1974) page 180.

C) Available Water:

The retention of water by a soil is determined not only by the pore size distribution in a soil but also by the amount of water present. When a soil is saturated, the retention forces are essentially zero. This means that water can be removed from the soil with minimal effort. However, as soon as appreciable amounts of water are removed from the soil by drainage, by deep percolation or by evaporation, retention forces begin to act in accordance with the principle of capillarity and make the water more difficult to remove.

This demonstration illustrates how capillary forces are governed both by porosity and by the amount of water present in capillary sized pores. The aim of this demonstration is to allow you to derive a definition of "available water" as it pertains to crop growth.

Equal weights of dry sand and clay soil will be wetted to achieve a range of water contents. The reference to be used for determining water content in this demonstration is field capacity (F.C.) -- the amount of water each soil will hold against the force of gravity. Pregerminated sorghum (*Sorghum bicolor*) seeds will be planted within a few millimeters of the soil surface in each treatment and grown for several days before class.

Table 4

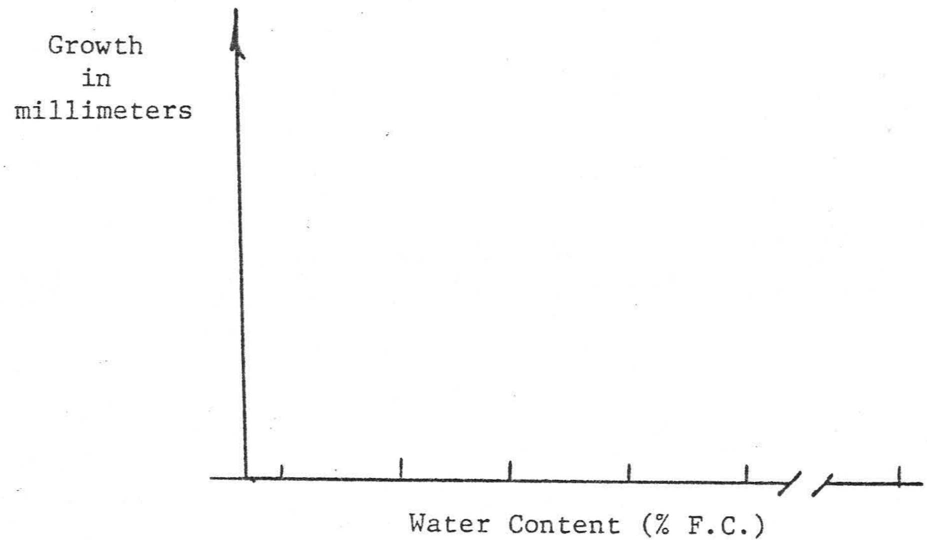
Growth Response to Water Content of Sand and Clay

WATER CONTENT (% Field Capacity)	SAND	CLAY	SAND	CLAY
	% Water (by volume)*		Growth (millimeters)	
Saturation				
F.C.				
75% F.C.				
50% F.C.				
25% F.C.				
0% F.C.				

*Note: Water content data will be provided by the instructor.

C) Available Water (continued)

Plot the growth responses (one for each soil) from the results in Table 4. Interpret the results in terms of the WATER RETENTION FORCES involved. Explain the difference in the growth response of seedlings in sand and in clay. Remember that plants must exert a force to absorb water from the soil environment; how is this reflected in your graph?



As water is drained or removed from a soil, the larger pores drain first and water is retained in the finer pores. The finer the pores, the greater the force required to remove the water.

With this in mind, write a DEFINITION OF "AVAILABLE WATER" as it pertains to crop growth.

C) Available Water (continued)

Questions:

1) Which of the soils in the above demonstration (clay or sand) holds the greatest amount of UNAVAILABLE water? Explain! (Hint: Study the water content data in Table 4.)

2) Does the greater amount of unavailable water in this soil indicate that it is a poor soil for crop growth? Defend your answer!

D) Soil Moisture Tension:

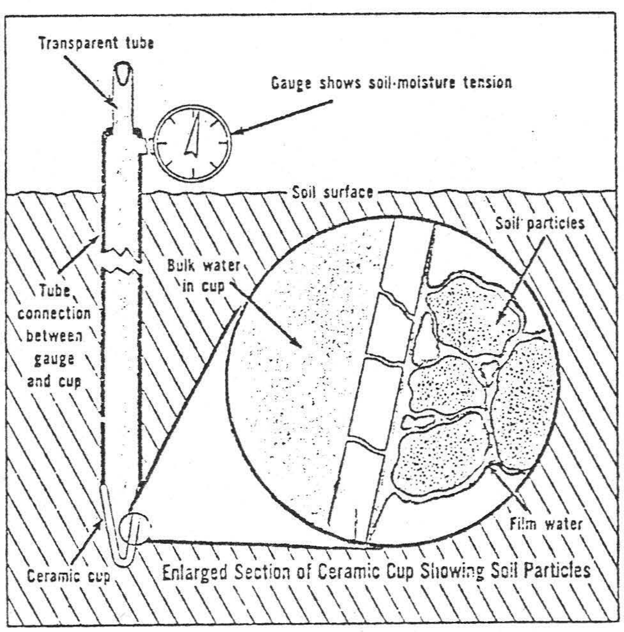
The forces involved in soil water retention can be quantitatively expressed in terms of tension. Tensiometers can be used to measure tensions directly in units of atmospheres, bars, or millimeters of mercury (mm Hg).

The basic features of a conventional tensiometer are diagramed in Figure 2 below. Inside the instrument is a water column that is completely sealed except for the bottom. At the bottom is attached a porous, ceramic cup that is placed in contact with the soil at the desired depth below the soil surface. The water in the column is thus allowed to "touch" the soil water surrounding the ceramic cup.

When the soil is saturated, the capillary forces in the soil are essentially zero, and the force (tension) exerted on the water column is also zero. As the soil dries, film water forms within the soil and capillary forces begin to act. Water is thus pulled through the ceramic cup and the force with which it is pulled is indicated on the vacuum guage at the top of the water column. When water from irrigation or rainfall is returned to the soil, the forces within the film water are reduced, water moves back into the ceramic cup, and the force acting on the water column is also reduced.

Figure 2

Soil Moisture Tensiometer



Photocopy from Richards and Hagan (1958).

D) Soil Moisture Tension (continued)

Research has shown that many crop plants grow best when the water content of the soil is at or near field capacity. At field capacity, the capillary forces in the soil are only a fraction of one atmosphere. Many crops, however, are grown in soils where year round soil moisture tensions are much greater than one atmosphere.

Is there an upper limit to the soil moisture tension that can be allowed in a crop community? That is, can soil moisture tensions become so high that the crop plant itself can not extract water from the soil? The answer is yes, although the upper limit varies somewhat from plant to plant. The following demonstration has been designed so that you can approximate this upper limit; the limit beyond which water becomes UNAVAILABLE for plant growth.

The instructor will prepare the demonstration by planting sunflower (Helianthus annuus) in pots which have equal weights of soil. A range of tensions will be established by allowing each pot to dry down to a given water content. Tensiometers will be installed in the moist pots. In other pots, Bouyoucos blocks will be installed to estimate the higher tensions which will develop in the relatively dry soils. Instruction in the Bouyoucos block method will be given in class. (Note: Conventional tensiometers cannot be used to measure high soil moisture tensions.)

Measure (or estimate) the tension in each of the pots and record the results in Table 5 below. The instructor will provide the necessary water content data for this demonstration.

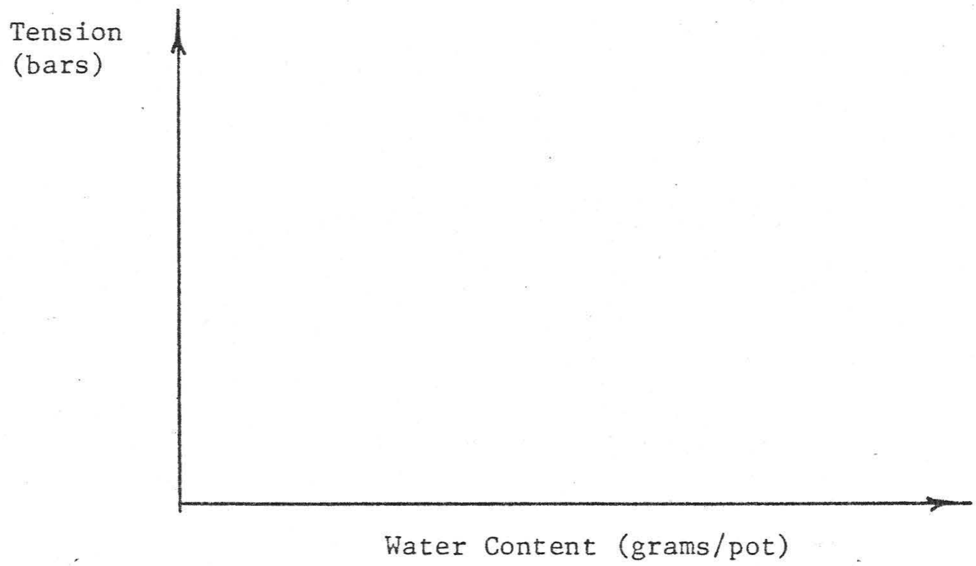
Table 5

Soil Moisture Tension and Water Content Data

Pot #	Water Content (grams water/pot)	Tension (bars)	Observations
1			
2			
3			
4			
5			
6			

D) Soil Moisture Tension (continued)

Using the data in Table 5, plot a soil moisture retention curve below. Such curves are often used in soil science to illustrate the relationship between soil moisture tension and gravimetric water content. They are particularly useful in comparing the water retention characteristics of soils having different textures, and hence, are sometimes called soil moisture characteristics curves.



Indicate the following moisture contents on the graph above:

1) saturation
2) field capacity
3) wilting range*
4) available water range

*Note: The wilting range is defined as the range of soil moisture from permanent wilting of the first leaves to the complete permanent wilting of the entire plant.

A clay soil was used for the above demonstration. Based on your knowledge of the water holding characteristics of clay and sand, can you predict the nature of a water release curve for sand? Sketch your prediction in the graph above.

REFERENCES AND SUGGESTED READING:

Brady, N. C. (1974). The Nature and Properties of Soils. MacMillan. 639 p. Chapter 7; "Soil Water; Characteristics and Behavior."

Foth, H. D. and L. M. Turk. (1972). Fundamentals of Soil Science. Wiley. 454 p. Chapter 4; "Soil Water."

Green, D. E. and D. G. Woolley. (1970). Soil Water -- Student Study Guide. In: Audio Tutorial Systems Agronomy Series. Burgess.

Richards, S. J. and R. M. Hagan. (1958). Soil Moisture Tensiometers; How it Works and How to Use it. A Cooperative Extension Bulletin. University of California at Davis.

INSTRUCTOR'S NOTES:

A) Materials and Preparation:

1) Demonstration of Soil Moisture Tension with Sunflower:

The preparation of this demonstration should begin at least five weeks before class.

Prepare a 1:1 mixture (volume basis) of perlite and clay soil. The Magoon area soil is well suited for this demonstration. A neutral soil of high fertility status and high clay content is recommended to minimize the need for ammendments and to insure good contact with the soil moisture tension instruments. Enough planting medium should be prepared to fill as many one-liter pots as are needed to plot a moisture release curve (page 12). At least six one-liter pots are suggested.

Plug the drainage holes in the one-liter pots with cotton. Fill the pots with EQUAL WEIGHTS of planting medium and dry 48 hours at 60 to 70 deg C. Measure the weight of each pot and determine the average dry weight.

Place the pots in a large, shallow pan of water and allow to saturate overnight. Measure the wet weight of each pot and determine the average wet weight at saturation.

Determine the average water content at saturation (grams per pot) by subtraction. This is the reference value needed to determine the water contents which will be recorded in Table 5 (page 11).

Plant several sunflower seeds per pot and thin after one or two weeks to two plants per pot. (Take care not to lose any of the planting medium from the pots.)

Allow the plants to grow in the greenhouse with optimum watering and sunlight. Take care to prevent excessively warm conditions, especially if black pots are used. When the plants are about four weeks old, determine the approximate rate of normal evapotranspiration per pot. This rate can be noted and used when planning the termination of watering described in c below.

A) Materials and Preparation (continued)

1) Demonstration of Soil Moisture Tension with Sunflower (continued)

In each of the pots which are to receive a low water content (high soil moisture tension) treatment, install a gypsum block for later attachment to a Bouyoucos Moisture Meter. In each of the pots which are to receive a high water content treatment, install a soil moisture tensiometer.

One week before class, allow the pots to saturate overnight by placing them in a shallow tray of water, as before. Weigh each saturated pot with its plants and gypsum block or soil moisture tensiometer. Record the weight on the outside of each pot. The desired range of soil moisture tensions can be established as follows:

a) Soil moisture tension equal to zero: One pot, having a soil moisture tensiometer, should be assigned this tension. Allow this pot to remain saturated by keeping it in a shallow tray of water. The water content of the pot will remain close to the average water content previously determined before planting.

b) Soil moisture tensions between 0 and 0.8 bars: Allow these pots, each having a soil moisture tensiometer, to dry down to the desired tensions. Monitor the gravimetric moisture loss from these pots and water as needed to maintain the desired tensions.

c) Soil moisture tensions greater than 0.8 bars: Allow these pots, each having a gypsum block, to develop soil moisture tensions in the range of 0 to 0.8 bars (i.e.; water contents similar to those of b, above). At periodic intervals before class, terminate the water supply to these pots to achieve the desired range of soil moisture tensions. For example, the highest soil moisture tension can be obtained by terminating watering five (5) days before class; the next highest soil moisture tension obtained by terminating watering four (4) days before class; etc.

Note: When watering is terminated, the pots should be at a state of low soil moisture tension, but not at a state of saturation since one or two extra days will be required for the evapotranspiration of larger quantities of water from a saturated soil. Knowing the approximate rates of evapotranspiration, the periodic termination of watering can be carefully planned. At least one pot should ultimately have a soil moisture content below the permanent wilting point. Other pots should exhibit both turgid and partially wilted plants.

A) Materials and Preparation (continued)

1) Demonstration of Soil Moisture Tension with Sunflower (continued)

When the pots are ready for class, the water content of each should be recorded on the pots. The water contents can be closely approximated by subtracting the gravimetric water loss from the average water content at saturation. It is suggested that large labels of the form shown below be used to identify each pot.

Weight of:	pot at saturation + plants + tensiometer (or gypsum block)	=	______	grams
Weight of:	pot at desired soil moisture tension + plants + tensiometer	=	______	grams
Weight of:	water lost	=	______	grams
Estimated water content		=	______	grams/pot

2) Demonstration of the Effect of Soil Tillage on Water Retention:

The preparation for this demonstration is described in PHYSICAL CHARACTERISTICS OF SOILS ("Instructor's Notes"; page 1b). Core samples and tensiometer readings are to be taken by the class during that session. The sample numbers should be recorded in Table 1 (page 3) and the tensiometer readings recorded in Table 3 (page 5).

The instructor can weigh and dry the core samples and provide the students with the wet weight data needed for Table 1. The instructor should also provide the students with core volume, and particle density data.

A) Materials and Preparation (continued)

3) Demonstration of the Effect of Texture on Available Water:

Eight to ten days before this session, sorghum seeds (about 500) and quartz sand (3.5 kg dry weight) and clay soil (3.5 kg dry weight) should be obtained for preparation. (Note: Alaeloa clay soil is well suited for this demonstration.)

Pregerminate the sorghum seeds on blotter paper.

The sand and clay soil should be oven dried. Using a 2 to 3 cm (inner diameter) glass tube, determine the volume of water that 100 cc of each soil will hold in the tube against the force of gravity. The values obtained can be arbitrarily designated as the volumetric water content at field capacity (F.C.). The range of water contents needed for this demonstration, as indicated in Table 4 (page 7), can be established using this value as a reference.

Put 500 grams of oven dry sand in each of six (6) 400 ml beakers. Determine the volume occupied by this amount of sand and add the appropriate amount of water to each beaker to establish the suggested range of water contents.

Put 500 grams of oven dry clay soil in each of six (6) 600 ml beakers and prepare the range of water contents as above.

Plant five or six sorghum seedlings in each beaker. The seedlings should be pregerminated with a combined radicle plus coleoptile length not longer than 1.0 cm. The seedlings can be placed horizontally between 0.5 and 1.0 cm below the surface to insure uniform and shallow planting. Planting should be done six to eight days before class.

Cover and seal each of the beakers with a one-liter plastic bag. The bags should be inflated to allow room for growth of the shoot and the beakers sealed just below their rims. Rubber bands can easily be used to form the seals.

The seedlings can be grown in a well lighted room or in a growth chamber at 20 to 25 deg C. Do not allow exposure to sunlight as this will increase the internal temperature of the beakers.

4) Demonstration of Capillarity with Microtubes:

A few glass microtubes of different diameters and a bottle of ink can be collected to illustrate the principle of capillarity.

A) Materials and Preparation (continued)

5) Summary of Instructional Materials for each Demonstration:

The materials which need to be gathered immediately prior to the classroom session for each of the demonstrations are listed below:

a) Soil Moisture Tension:

i) Set of pots with sunflower, each pot having a different soil moisture tension and an installed tensiometer or gypsum block. Each pot should be labeled to identify its water content.

ii) Bouyoucos Moisture Meter with batteries.

iii) Bouyoucos Moisture Meter Chart to determine the soil moisture tension for a given meter reading. A photocopy of the chart from the operating manual for the Bouyoucos Meter is given on page 1f. The chart, or the operating manual (or both) should be on hand during the session.

b) Water Retention:

i) Oven dried core samples in labeled moisture cans.

ii) One or two balances for weighing core samples.

iii) Several spatulas for scraping soil from rings.

iv) Trash cans for disposing of dry soil.

v) Desk- or portable-calculator for calculating entries to Tables 1 & 2 on pages 3 & 4, respectively.

c) Available Water:

i) Both sets of demonstration treatments (i.e.; seedlings grown in sand and in clay soil) with beakers sealed and clearly labeled to identify:

- water content (% F.C.).
- water content (% volume).
- mass of dry soil (grams).

ii) Several metric rules for determining shoot growth.

d) Capillarity:

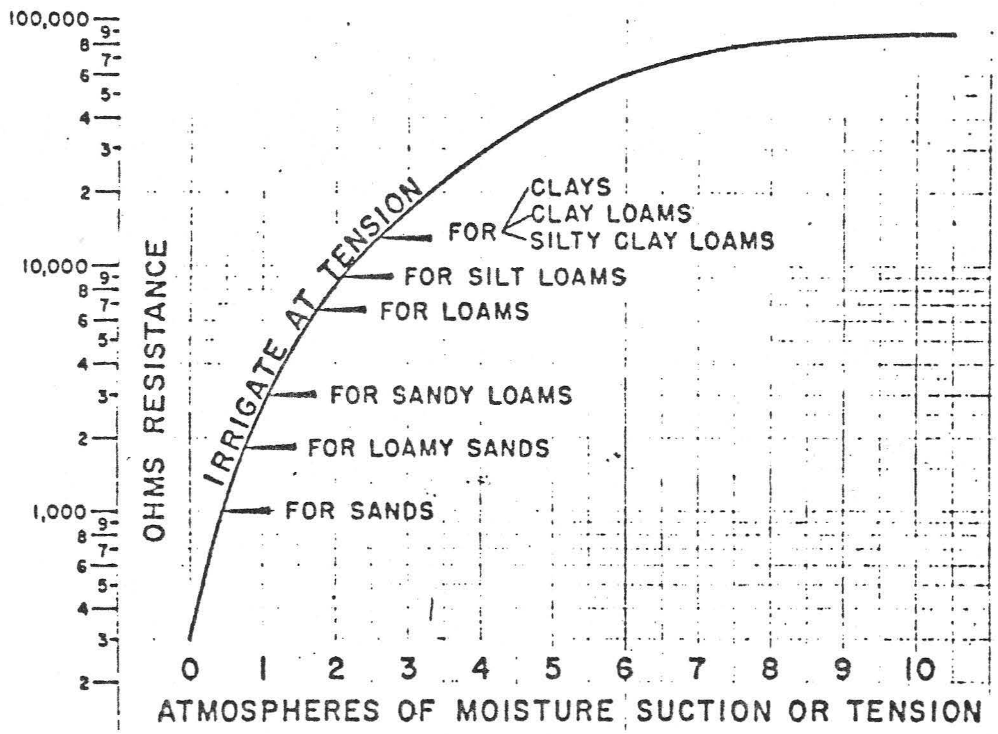
i) Bottle of ink.
ii) Glass microtubes of different diameters.

A) Materials and Preparation (continued)

5) Summary of Instructional Materials (continued)

A copy of the chart given below must be on hand to determine the soil moisture tensions in the pots having a gypsum block attachment for the Bouyoucos Moisture Meter.

Bouyoucos Moisture Meter Chart



Photocopy from Industrial Instruments Inc. (1962) Operating Manual for Soil Moisture Testing--Bouyoucos Moisture Meter and New Improved Soil Blocks. Industrial Instruments Inc., Cedar Grove, New Jersey. 12 p.

B) Presentation (A three-hour, demonstration-oriented session):

All the activities for this session are derived from prepared demonstrations. The instructional materials for each demonstration can be divided among classroom tables and work benches.

Only the demonstration of capillarity requires no data collection. This demonstration can be used as a focusing point in formal discussion with the class; perhaps during the opening minutes. The concept of capillarity is of central importance in all the activities.

Some time should be taken to show the class how a tensiometer works and how it is normally installed in the field and to discuss the principle of measuring tensions indirectly with a Bouyoucos Meter. During this discussion, the data for the soil moisture tension demonstration might be collected by the class as a whole.

The seedlings in the available water demonstration should be covered with the plastic bags until presentation to illustrate how the water contents were maintained. The students can develop their own procedure for measuring shoot growth. Students should be asked not to destroy any of the seedling material before others have had a chance to collect data.

The data from the tillage demonstration should be recorded on the blackboard. Since students will have to divide the core samples among themselves to measure dry weights, their measurements can be reported on the board for others to record. The wet weight, core volume, and particle density data in Table 1 must be provided by the instructor.

C) Suggestions:

When dealing with soil moisture tension, it is suggested that units of bars be used consistently. This lends itself to a better understanding of the tensions involved in both soil-water and plant-water relationships and avoids having to translate the units involved.

In keeping with the "Instructional Objectives," it is suggested that formal definitions NOT be discussed until students have had the chance to make their own interpretations. Hence, terms such as "field capacity," "available water," "wilting range," and "soil moisture tension" should be dealt with conceptually rather than formally. Indeed, formal definitions of these and other related terms are the subject of other courses and should be left as such.

SEED GERMINATION AND SEEDLING ESTABLISHMENT

OBJECTIVES:

A) Instructional Objectives:

The majority of the world's field crops are grown from seed. For this reason, the principles and techniques of propagating crop plants by seed constitute an important area of agricultural research and technology.

This session is designed to introduce some of the basic characteristics of seeds and seedling development. During the session, you will examine both seeds and seedling materials representative of two important crop families -- the legumes and the grasses. Work stations will be set up by the instructor and the activities at each station will enable you to:

1) IDENTIFY the major parts of a seed and DESCRIBE the role of each in germination.

2) LOCATE and IDENTIFY the following:

   a) The active site of respiration in a "live" seed.
   b) The growing points of a grass and a legume seedling.
   c) The active regions of seedling elongation.

3) COMPARE epigeal and hypogeal emergence.

4) LIST the major differences in the establishment of a legume and a grass seedling.

B) Terminal Objective:

At the end of this session, you should be able to report in your field book the percent (approximate) emergence and the percent establishment of the crop in your plot experiment with respect to the total number of seeds planted; and you should be able to evaluate the influence of the following on both emergence and establishment: 1) seed quality. 2) environmental hazards (eg.; insects, disease, birds, weather, etc.). 3) physical characteristics of the soil.

WORKSHEET:

A) The Mature Seed:

A mature seed consists of an embryo and storage tissues, both enclosed by a protective seed coat. Seeds vary greatly in appearance, size and shape. The location and structure of the embryo and the nature of the storage tissues also vary. Cross sections of seeds of six crop species are diagramed in Figures 1a and 1b on page 3.

Several important and distinguishing features characterize the seeds of all crop plants:

The seed embryo has two growing points, the shoot apex and the root apex, located at opposite ends of the embryo axis. The embryonic shoot apex is called the plumule and consists of the first leaves of the new plant and undifferentiated shoot tissue. The embryonic root apex is called the radicle.

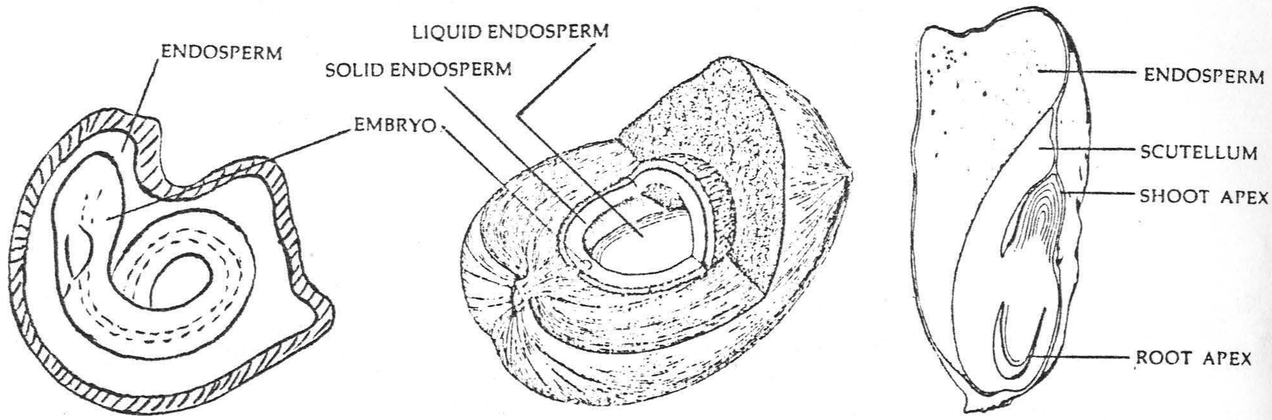
One or two leaf-like structures called cotyledons are attached to the embryo axis. Flowering plants are classified as monocotyledons or dicotyledons according to the number of cotyledons in their seed. The cotyledons of many dicotyledenous species are the dominant feature of the seed. Examples include seeds of common legume crops such as soybean, pea and the common bean.

Monocotyledenous plants have a single counterpart to the cotyledons of dicots. In grass seeds the cotyledon is called the scutellum. In corn, the scutellum is a prominent embryonic feature.

The endosperm is nutritive tissue which surrounds the embryonic plant during its development and may remain as a reserve food source until it is used by the seedling during germination. In some seeds, such as corn, coconut and castor bean, the endosperm is a dominant feature. In other seeds, such as beet, soybean and the common bean, the endosperm is reduced to a thin layer or absorbed completely during embryo development.

Figure 1a

Seed Structures of Three Monocot Species



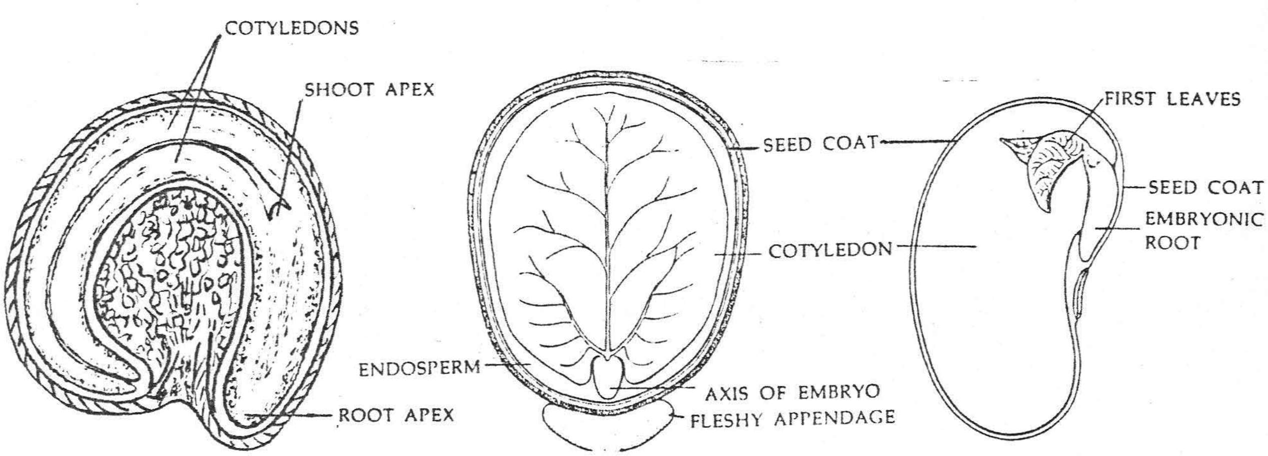
onion,
Allium cepa

coconut,
Cocos nucifera

corn,
Zea mays

Figure 1b

Seed Structures of Three Dicot Species



beet,
Beta vulgaris

castor bean,
Ricinus communis

common bean,
Phaseolus vulgaris

A) The Mature Seed (continued)

Activity -- Comparing the Chemical Composition of Seed Storage Tissues:

1) Iodine colors starch grains dark purple or black.

Cut the seeds of soybean, pea and corn in half CUTTING THROUGH THE ENDOSPERM OR COTYLEDON TISSUES. Place a drop of iodine solution on the freshly exposed surfaces. The presence of starch is indicated by a purple coloration.

Observations:

CORN --

SOYBEAN --

PEA --

2) Protein precipitates in the presence of trichloroacetic acid.

Separate the embryonic section of a soaked corn seed with a sharp blade and discard. Crush the endosperm in about 10 ml of water. Allow to settle.

Remove and discard both the seed coat and the embryo from a soaked soybean seed and a soaked pea seed. Crush the cotyledons of each in separate beakers containing 10 ml of water. Allow to settle.

Decant the liquid from each of the three preparations into one of three small test tubes. Add one or two drops of trichloroacetic acid (TCA) to each and compare. EXERCISE CAUTION WHEN USING TCA as it is both caustic and poisonous!

Observations:

CORN --

SOYBEAN --

PEA --

A) The Mature Seed (continued)

Question:

Starches and proteins are two different classes of biochemical material and are used by plants for different purposes. Starches are principally used as stored food. Proteins, however, have many functions which include physical structure, transport and storage of food, and enzyme catalysis in biochemical processes. With this in mind, what do you suppose is significant about the differences observed in the preceding activity.

B) Germination:

A mature seed germinates from a quiescent or dormant state. Germination occurs when any existing dormancy is broken and a suitable environment is provided. The environmental requirements for germination are:

1) Water for the hydration of cells and the breakdown and transport of stored food.

2) Oxygen for respiration.

3) Adequate temperature for metabolism.

Activity -- Locating the Active Site of Growth in "Live" Seeds:

Tetrazolium changes to an insoluble red compound in the cells of respiring tissues.

Cut a dry corn kernal into two halves, CUTTING LONGITUDINALLY ALONG THE EMBRYO AXIS. Remove and discard the seed coat from a soybean seed and separate the embryo and the cotyledons. Drop the halves of the corn kernal, the soybean cotyledons and the soybean embryo into a small beaker of tetrazolium chloride solution.

Observations:

B) Germination (continued)

Questions:

1) What conclusions can you make (from the tetrazolium test) about the active site of oxygen consumption in germinating seeds?

2) Can the tetrazolium test be used to determine seed viability? If yes, how? If no, why not?

3) During the first stage of germination, what must be a necessary feature of the seed coat for favorable environmental conditions to be effective?

C) Seedling Emergence:

Two types of seedling emergence occur: hypogeal emergence and epigeal emergence.

1) In hypogeal (hypo-, below) emergence, the cotyledons remain below the surface of the ground. Crop plants having hypogeal emergence exhibit their first true leaves upon the exposure of the plumule to light. The emerging plumule in grasses is protected by the coleoptile, which acts as a sheath and elongates until exposed to light and then allows the new leaves to unfold from within. Hypogeous dicots such as pea have no such protective structure for the emerging plumule.

2) In epigeal (epi-, above) emergence, the cotyledons are raised above the surface of the ground. Epigeal emergence is characterized by the elongation of the hypocotyl, the portion of the seedling axis directly below the cotyledonary node. The hypocotyl thus lifts the cotyledons together with the enclosed plumule above the ground. Epigeal emergence is most often found among dicots and is further characterized by a hypocotyledonary arch which reaches the surface of the ground ahead of the plumule and straightens upon exposure to light. Soy bean and the common bean exhibit epigeal emergence and the hypocotyledonary arch identifies their so-called "crook" stage of emergence.

Activity; Comparison of Seedling Emergences:

Diagram the seedling emergence stage for each of the plants indicated on pages 7 and 8. Identify the structures listed and make appropriate comparisons. Laboratory specimens are available for this activity.

Figure 2a

Seedling Emergence Stage in Corn

(Germination 10 cm from Surface)

coleoptile

endosperm

scutellum

radicle

Figure 2b

Seedling Emergence Stage in Corn

(Surface Germination)

coleoptile

endosperm

scutellum

radicle

Figure 3a

Crook Stage of Emergence in Soybean

(Epigeal Emergence)

cotyledons

hypocotyledonary arch

hypocotyl

radicle

Figure 3b

Plumule Emergence Stage in Pea

(Hypogeal Emergence)

plumule

cotyledons

radicle

C) Seedling Emergence (continued)

Questions

1) Is corn emergence epigeal or hypogeal?
Explain!

2) How are the structure and function of the scutellum different from the structure and function of the cotyledons of a legume?

How are the scutellum and cotyledons similar?

3) Why will corn usually emerge from greater depths than will soybean?

D) Seedling Establishment:

Seedling morphology varies both with species and with depth of planting. Variations occur in the emergence of leaves from the shoot apex, in the development of the root systems, and in the elongation of the seedling axis.

Activity; Study of Seedling Morphology:

Use the following pages to make and label diagrams of the seedling establishment stages indicated. Make appropriate comparisons. The table below can be completed as part of this activity.

Comparison of Seedling Establishment
in Corn, Soybean and Pea

	CORN	SOYBEAN	PEA
Food supply during germination and establishment			
Major functions of cotyledons			
Type of emergence			
Position of terminal bud at establishment			
Major root system at establishment			

Figure 4a

Leaf Emergence Stage in Corn
(Germination 6 cm. from Surface)

coleoptile

growing point
--region of active growth within the shoot apex from which leaves emerge

mesocotyl (first internode)
--region of seedling axis between the scutellar node and the point of attachment of the coleoptile

primary root system
--the radicle and seminal roots which originate below the scutellar node. The primary root system is of major importance only during seedling establishment.

Figure 4b

Leaf Emergence Stage in Corn
(Surface Germination)

coleoptile

growing point

mesocotyl

primary root system

Figure 5a

Two Leaf Stage in Corn
(Germination 6 cm. from Surface)

first and second leaves

growing point

coleoptile

mesocotyl

adventitious roots
--These roots develop in the area where the coleoptile joins the mesocotyl. They make up the secondary root system -- the principle root system after about three weeks of seedling growth.

primary root system

Figure 5b

Two Leaf Stage in Corn
(Surface Germination)

first and second leaves

growing point

coleoptile

mesocotyl

adventitious roots

primary root system

Figure 6a

First True Leaf Stage in Soybean
(Epigeal Emergence)

growing point

first true leaves

epicotyl
--region above the cotyledonary node

cotyledonary node

hypocotyl

primary root
--develops into the central axis (taproot) of the plant root system.

Figure 6b

First True Leaf Stage in Pea
(Hypogeal Emergence)

growing point

first true leaves

epicotyl

cotyledons

hypocotyl

primary root

Figure 7a

First Trifoliolate Leaf Stage in Soybean

growing point

trifoliolate leaf

unifoliolate leaf

axillary buds

taproot

secondary root

Figure 7b

Seedling Establishment Stage in Pea

growing point

complete leaf

--having both petiole and blade

incomplete leaf

first internode
--determined from cotyledonary node

taproot

D) Seedling Establishment (continued)

Questions

1) How is the mesocotyl important in the emergence of the plumule of corn from deep in the soil?

2) What environmental conditions must be added to those required for germination (page 4) as the seedling becomes a photosynthetic organism?

3) Can root pruning by cultivation be avoided by the deep planting of corn seed? Explain!

4) Are the growing points of legume seedlings and grass seedlings equally vulnerable to say:

   a) frost or mechanical injury?

   b) soil applied herbicides?

REFERENCES AND SELECTED READINGS:

Foster, A. S. and E. M. Gifford, Jr. (1974). Comparative Morphology of Vascular Plants. W. H. Freeman. 751 p.
Chapter 21; "Fruits, Seeds and Seedlings." Onion seed in Figure 1a was redrawn from this chapter.

Hanway, J. J. (1971). How a Corn Plant Develops. Special Report No. 48. Iowa State University. 17 p.

__________ and H. E. Thompson. (1971). How a Soybean Plant Develops, Special Report No. 53 (Rev.). Iowa State University. 17 p.

Hartman, H. T. and D. E. Kester. (1975). Plant Propagation Principles and Practices. Prentice-Hall. 662 p.
Chapter 6; "Principles of Propagation by Seeds."
Chapter 7; "Techniques of Propagation by Seeds," gives a discussion of the use of tetrazolium chloride.

Hayward, H. E. (1938). The Structure of Economic Plants. MacMillan. 674 p.
Chapter IX; "Chenopodiaceae Beta vulgaris." Beet seed in Figure 1b was redrawn from this chapter.

Purvis, M. J., D. C. Collier and D. Walls. (1966). Laboratory Techniques in Botany. Butterworths. 439 p.
Chapter 6; "Some Useful Tests for Biologically Important Substances."

Raven, P. H. and H. Curtis. (1970). Biology of Plants. Worth. 706 p.
Chapter 2-2; "The Biography of an Angiosperm." Seeds of corn, castor bean and the common bean in Figure 1 were photocopied from this chapter.
Chapter 6-8; "Evolution of the Flowering Plants." Coconut seed in Figure 1a was photocopied from this chapter.

INSTRUCTOR'S NOTES:

A) Materials and Preparation:

Four activities are included in this session. The preparation and the instructional materials needed for each are described below. Each activity can be set up at a designated work-station.

1) Seedling Establishment:

The preparation of seedling materials for this activity should begin two to three weeks before class. The preparation consists of periodically planting corn, soybean and pea in germination trays or in pots. Perlite and vermiculite are good planting media. One method of preparation which facilitates the identification of the depth of planting is to place the seeds on a layer of perlite and cover with the required amount of coarse vermiculite. Several seeds of each variety should be planted at desired intervals. Sufficient spacing should be allotted to prevent the entanglement of roots. (The seedlings must be uprooted for study during class.)

The preparation includes two planting depths for corn. In one case, corn should germinate within one or two centimeters of the surface; the seeds should be covered with only enough planting medium to conserve moisture for germination. In the second case, corn should germinate from 10 cm below the surface. The idea here is to promote the elongation of the coleoptile and the mesocotyl. Light will inhibit the elongation. Vermicullite, which minimizes light transmission, is again suggested for coverning the seeds. Sections of black plastic can also be used, but they should be removed upon seedling emergence.

The suggested planting intervals are two weeks, one week, five days, three days and two days before class.

A set of seedling materials at two establishment stages can be layed out on blotter paper at a designated work-station. The materials are:

a) Deep germinated corn at the leaf emergence stage and at the two-leaf stage.

b) Surface germinated corn at the leaf emergence stage and at the two-leaf stage.

c) Soybean at the first true-leaf stage and at the first trifoliolate leaf stage.

d) Pea at the first true-leaf stage and at the establishment stage.

A) Materials and Preparation (continued)

2) Seedling Emergence:

The above preparation will also supply seedling materials for this activity. The following materials should be layed out on blotter paper at a separate work station:

a) Deep germinated corn seeds with elongated, unopened coleoptiles and elongated mesocotyls.

b) Surface germinated corn seeds with short, just-opened coleoptiles. The seedlings are at the stage which immediately precedes the leaf emergence stage. The mesocotyls will be short and difficult to observe.

c) Germinated soybeans at the crook stage of emergence.

d) Germinated peas at the plumule emergence stage.

3) The Mature Seed:

About a dozen corn, soybean and pea seeds should be soaked overnight in preparation for this activity. The work-station materials required for this activity are:

a) Soaked corn, soybean and pea seeds.

b) Dropper bottles with iodine in potassium iodide solution. The solution can be prepared by dissolving 2 grams of potassium iodide in as little water as possible and then dissolving one gram of iodine. The solution is made up to 100 ml with distilled water.

c) Trichloroacetic acid solution (10%).

d) Test tubes (several).

e) Glass stirring rods (several).

f) Wash bottles with distilled water (one or two).

g) Dissecting blades or razor blades (several).

4) Germination:

About a dozen corn and soybean seeds should be soaked in a clean beaker of boiled, distilled water for one hour before class. The work-station materials required for this activity are:

a) Soaked corn and soybean seeds.

b) Flask of tetrazolium chloride solution (1% at pH 6 to 7). The flask must be clean!

c) Dissecting blades or razor blades (several).

d) Test tubes or 50-ml beakers (several). These must be clean!

B) Presentation (A three-hour, work-station, activity session):

This session was primarily designed to allow students to familiarize themselves with the major morphological characteristics of crop seeds and seedlings. Actual seed and seedling material is the essence of the presentation.

The activities can be completed at each student's own pace. Most of the activities involve diagramming the plant material. To help students avoid unnecessary artistic endeavors, illustrate the use of stick or skeleton diagrams. Inform them that the diagramming is to help them become familiar with the actual appearance of the structures indicated in the Worksheet.

C) Suggestions:

The use of a formal discussion during this session is left to the discression of the instructor. However, it is felt that for the activities to be of most value, the instructor should concentrate on assisting students on an informal basis at the work-stations. Past experience in the development of this session has shown that much individualized assistance is needed for two reasons:

1) Students who have not been exposed to the actual plant material before are often hesitant to identify and label the plant structures. Individualized assistance in this regard is much appreciated.

2) Students often label structures incorrectly. Individualized guidance in this regard is, therefore, an instructional necessity.

A final suggestion pertains to the use of published diagrams, pictures, etc. Such material is not necessary and should not be present at the work-stations. Some students, however, are interested in publications for supplemental reference. The following may be of particular value to those who are conducting a plot experiment with corn or soybean:

Hanway, J. J. (1971). How a Corn Plant Develops. Special Report No. 48. Iowa State University. 17 p.*

Hanway, J. J. & H. E. Thompson. (1971). How a Soybean Plant Develops. Special Report No. 53 (Rev.). Iowa State University. 17 p.*

*Available from Publications Distribution, Printing and Publications Building, Iowa State University, Ames, Iowa, 50010.

FLOWER STRUCTURE AND SEED DEVELOPMENT IN GRASSES AND LEGUMES

OBJECTIVES:

A) Instructional Objectives:

The grasses (Gramineae) and the legumes (Leguminosae) are two of the largest families of flowering plants and are the two most important sources of human food. The cereal grains of the grass family are the staple diet of most of the world's population. The edible seeds of the legume family are an important source of protein.

Grain and seed yield depend on the production and pollination of flowers in a crop community. A laboratory session will be prepared to allow you to become familiar with the primary characteristics of grass and legume flowers and to examine the role they play in pollination and seed development. Specimens of several grasses and legumes will be provided for study. (The instructor may have you collect some of the specimens on your own.) Before the end of the session, you should be able to:

1) IDENTIFY the parts of a grass spikelet and GIVE examples of grass species having perfect florets and species having imperfect florets.

2) IDENTIFY the parts of a legume flower.

3) DISCUSS the role of the two most important pollinating vectors in grass and legume communities and DESCRIBE the structural adaptations of several species to each vector.

4) COMPARE seed development in grasses and legumes in terms of the following:

    a) origin of the embryo.
    b) origin of the endosperm.
    c) origin of the seed coat.
    d) origin of the seed enclosures.

B) Terminal Objective:

At the end of this session, you should be able to describe the floral characteristics of the crop in your plot experiment, and you should be able to report experimental conditions which may affect both pollination and fruit and seed development in the experiment.

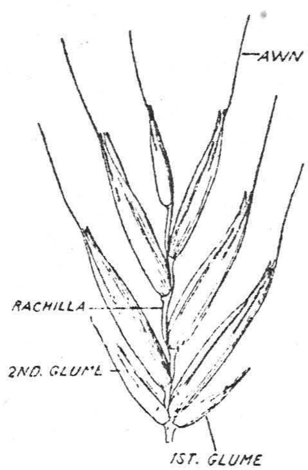
WORKSHEET:

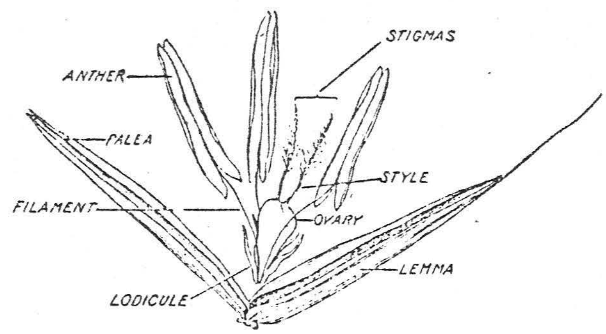
A) The Grass Spikelet:

The spikelet is the smallest unit of the inflorescence in the grasses. A spikelet consists of one to several florets subtended by a pair of bracts known as the glumes. Each fertile floret contains a flower that is enclosed by two distinctive bracts of its own; the lemma and the palea. The lemma is easily identified as the outer bract and the palea is directly opposite. A typical grass spikelet and an opened floret are diagrammed below.

Figure 1

Diagram of a Spikelet and One of its Florets





Photocopy from Dayton (1948), page 638.

A grass floret can be perfect, imperfect or sterile. A perfect floret, such as in Figure 1 above, has both pollen producing stamens and an egg producing pistil. Imperfect florets have only one or the other. Sterile florets have no functional reproductive structure.

The stamens of the grass floret are typically three in number and consist of slender filaments and long, two-celled, pollen-bearing anthers. The pistil consists of a one-celled ovary and usually two styles and stigmas. At the base of the reproductive structures of many grass florets are two or more appendages known as the lodicules which swell at the time of anthesis (flower opening) and force apart the lemma and the palea to allow the emergence of the anthers and the stigmas.

A) The Grass Spikelet (continued)

Activity -- Examining the Features of the Spikelet:

Identify the parts of a grass spikelet from two or more species available in the lab. Use the dissecting microscope, a dissecting needle and a pair of tweezers to locate and examine each of the principle structures introduced on page 2.

IDENTIFY THE GLUMES FIRST as these are the defining elements of the spikelet. Note: The spikelet may be pedicelate, as in sorghum, or sessile (having no pedicel) as in wheat and in the female inflorescence of corn. Each pair of glumes is attached to the base of the spikelet at a single node.

Open the spikelet to determine the number of florets. Sterile florets are usually much smaller than fertile florets and are typically raised on a minute pedicel of their own.

Finally, separate the lemma and the palea of a single floret and identify the reproductive structures enclosed. Note: If the specimen was collected at anthesis, the lodicules may appear as swollen tissues and should not be confused with the ovary.

Ask for the instructor's assistance at any time!

Complete the following check-list.

Specimen		Floret examined		
Common name	Scientific name	staminate	pistillate	perfect

SAVE YOUR PLANT MATERIAL! Do not discard anything as you may wish to examine some of the structures again in a later activity.

B) The Legume Flower

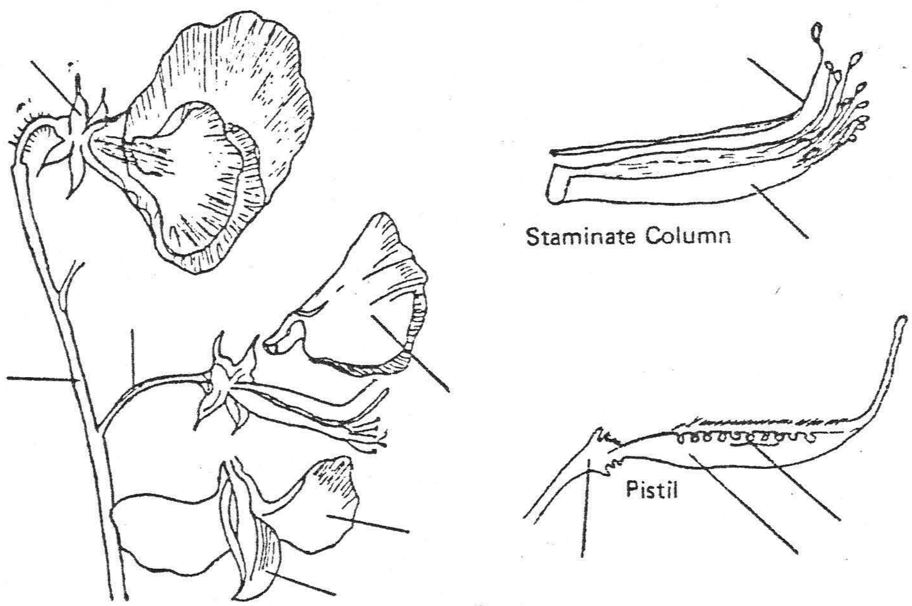
The typical legume flower consists of 5 sepals, 5 petals, and the reproductive structures within. The petals are identified as the banner (upper), the lateral wings (sides), and the keel (two fused lower petals). The flowers are pedicillate and usually arranged along a central axis to form a "raceme" type of inflorescence.

Most legumes have perfect flowers. Several stamens surround the ovary. The style may be longer or shorter than the stamens. Unlike the grasses, the number of ovules contained in the ovary varies with the species.

The reproductive parts and the arrangement of the sepals and petals in a typical legume flower are diagrammed below.

Figure 2

Diagram of a Typical Legume Flower
(Label the structures indicated!)



Photocopy from Larson, Russel and Nelson (1975), page 59.

B) The Legume Flower (continued)

Activity -- Examining "Typical" Legume Flowers:

Examine and compare the structure of two or more legume flowers. You may wish to compare a large flower from a plant like rattle pod (a noxious weed) or garden pea and a small flower from a plant like soybean. Use the dissecting scope when necessary.

Complete the following table. Note in particular the spatial relationship among the keel, the anthers and the stigmas.

Specimen		Observations
Common name	Scientific name	

C) Pollination:

Pollination refers to the transfer of pollen from anther to stigma. Self-pollination refers to the transfer of pollen to the stigma of a flower on the SAME PLANT. Cross-pollination refers to the transfer of pollen to the stigma of a DIFFERENT PLANT of the same species.

Every crop manager should know the type of pollination that normally occurs in the field crops he is working with. If he intends to use the seed from the crop for planting material, he should be aware that cross-pollination can result in the introduction of "new" plant characteristics; and that self-pollination results in the "segregation" of plant characteristics. He should also be aware that cross-pollinating species require the presence of pollinating vectors at anthesis to insure adequate pollination for high seed yield. Wind and insects are the two most important pollinating vectors in field-crop communities.

The structural features and the spatial arrangement of the anthers and the stigmas in both grasses and legumes is highly determinant of the type of pollination that normally occurs.

Activity -- Comparing the Structural Adaptation of Flowers to Cross-pollination:

Use the dissecting scope to examine and compare the stigmatic surfaces of two grasses and two legumes that are cross-pollinating to an appreciable degree. Note your observations in the table below.

Specimen		Observations
Common name	Scientific name	

C) Pollination (continued)

Many grasses and legumes are highly self-pollinated because of the proximity of the anthers to the stigma of the same flower and because of the protective enclosures which prevent cross-pollination by wind and insects. In wheat, for example, a high degree of self-pollination occurs because the pollen is released from the anthers before the lemma and the palea fully open. The pollen, then, is caught on the stigma of the same floret. Many of the legumes also self-pollinate before the flowers completely open. It is easy to see how the keel prevents cross-pollination in this regard.

Questions:

1) The stigma of a typical grass floret is described as "feathery." What is the advantage of a feathery stigma?

2) Is self-pollination assured by a perfect flower? Explain!

3) Plants with staminate and pistillate structures borne separately (i.e.; in different flowers) but on the SAME PLANT are called monoecious (Gk. monos, single + oikos, house). Is cross-pollination assured in a monoecious species? Explain!

Note: Most grasses and legumes have perfect flowers. A few, such as corn are monoecious.

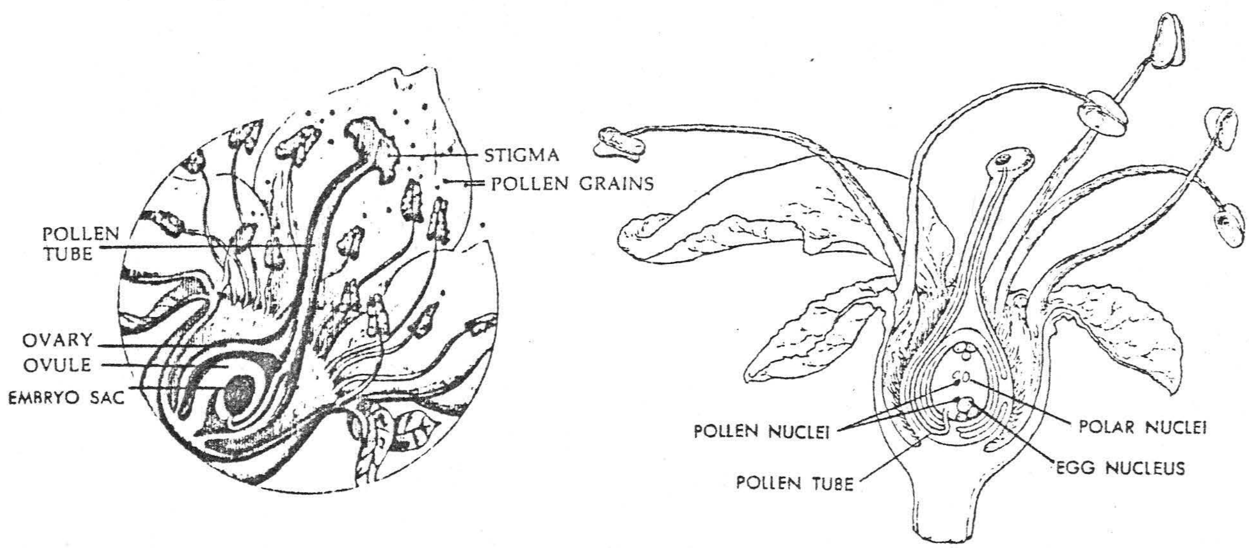
D) Fruit and Seed Development:

The so-called "fruits" of flowering plants are derived from the ovary tissues and sometimes even accessory tissues such as the receptacles and the petals. Many different types of fruits exist due to the differences in the maturation of tissues surrounding their seeds. In grasses, the seed and the fruit are synonymous. In legumes, the fruit develops as a pod containing several seeds.

A review of the primary structures involved in the process of fruit growth and development is useful here to help point out the similarities and differences between the seeds of grasses and legumes. Some of the principle flower structures discussed are given in Figure 3.

Figure 3

The Flower During Fertilization



Left: Photocopy from Raven and Curtis (1970), page 159.
Right: Photocopy from Baile (1954), page 41.

Pollen, if it is compatible with the stigma on which it falls, sends out a thread-like tube which grows down through the style and into the embryo sac of a single ovule. Within the pollen tube are two generative nuclei. One fuses with the egg nucleus of the embryo sac to form the zygote which develops into the embryo of the new seed. The other generative nuclei fuses with two polar nuclei to form the beginnings of the endosperm. Thus, the embryo and the endosperm result from what is known as DOUBLE FERTILIZATION -- a process characteristic of most flowering plants.

D) Fruit and Seed Development (continued)

Two important features of a ripe seed in relation to the flower in which it is borne are now apparent:

1) The embryo and the endosperm develop within a single ovule. Both the embryo and the endosperm carry genetic material from both parents.

2) The seed coat of the mature seed arises from the ovary tissues of the female parent and carries genetic material from that parent exclusively. In grasses, the seed coat develops from the tissues of the ovary wall and is called the pericarp. The seed coat of a leguminous seed develops from the integuments (enclosing tissue) of the ovule and is called the testa.

Activity -- Tracing Seed Development in Grasses and Legumes:

The instructor will provide plant material illustrative of the various stages of seed development in grasses and legumes. Trace the development of the pod from the flowering stage in two or more legume species. Also trace the development of the caryopsis (kernal) from the flowering stage in two or more grass species.

Questions:

1) What does the pod develop from in the legumes?

2) What are the enclosures of the caryopsis in Graminae?

REFERENCES AND SELECTED READINGS:

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Chase, A. (1948). The meek that inherit the earth. In: The Yearbook of Agriculture. U. S. Department of Agriculture. pp 8-15.

Dayton, W. A. (1948). The family tree of Gramineae. In: The Yearbook of Agriculture. U. S. Department of Agriculture. pp 637-639.

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Purseglove, J. W. (1968). Tropical Crops Dicotyledons. John Wiley & Sons (Halsted Press). 719 p.

______________. (1972). Tropical Crops Monocotyledons. John Wiley & Sons (Halsted Press). 607 p.

Raven, P. H. and H. Curtis. (1970). Biology of Plants. Worth. 706 p. Chapter 2-2; "The Biography of an Angiosperm."

INSTRUCTOR'S NOTES:

A) Materials and Preparation:

This session is one of the easiest to prepare. It does, however, require early and periodic planting of certain cereals to provide both flower and seed specimens of graminaceous crops. Suggested species and times of planting are as follows:

1) Rice (Oryza sativa), 120-day variety. Plant at least four months before class for fully matured specimens. This plant grows well in one-gallon containers. Plant several pots every week for five weeks. Soak seeds 48 hours before planting. Thin plants to one per pot and water liberally.

2) Corn (Zea mays), 90-day variety. Plant one row three months before class and one row every week thereafter for five weeks.

3) Sorghum (Sorghum bicolor), 90-day variety. Plant one row three months before class and one row every week thereafter for five weeks.

Note: Two grass species which are cross-pollinated by wind are required for the laboratory activities.

Legume flowers and seeds can be collected from wild plants and, with permission from the Botany Department, from the courtyard and planters around St. John Building. Specimens collected in the past included the following:

1) Creeping indigo (Indigofera endecephalla).
2) Crotalaria (Crotalaria mucronata).
3) Indigo (Indigofera suffruticosa).
4) Kaimi clover (Desmodium canum).
5) Pigeon pea (Cajanus sativa).
6) Siratro (Phaseolis atropurpureas).

Note: Two legume species which are cross-pollinated by insects (and have the typical legume flower structure) are required for the laboratory activities. Several of the legume specimens can be collected by the students themselves.

A) Materials and Preparation (continued)

The following materials need to be collected for the laboratory session:

1) Inflorescences and developing fruits of several grass and legume species labeled according to:

   a) Family name.
   b) Plant name -- common and scientific.
   c) Stage of development -- A complete spectrum is required; i.e.; from anthesis or anther dehiscence to ripe or fully filled seed.

   Note: Enough plant material should be collected to allow each student to work in pairs or independently with the specimens.

2) Dissecting microscopes. At least one scope for every two students is recommended.

3) Dissecting blades -- one per scope.

4) Dissecting needles -- one per scope.

5) Tweezers -- one per scope.

B) Presentation (A three-hour laboratory session):

A useful way of introducing this session is to talk about the inflorescence types represented by the laboratory specimens. For example, the differences between a panicle (eg.; sorghum) and a spike (eg.; corn) can be shown and the students thus introduced to the meaning of "pedicillate" and "sessile." The typical raceme inflorescence of the legume can also be shown. Students whose independent study project deals with soybean can be asked to verify for themselves whether its inflorescence is indeed a raceme type. Stick diagrams of these three inflorescence types can be drawn on the board. It is also useful for discussion purposes later in the laboratory to define the "rachis" -- a term used for the central axis of all three inflorescence types.

Before proceding with the student activities, make sure the students are familiar with the dissecting microscope. Review the features of the scope and ask that caution be exercised at all times.

The student directives for the laboratory activities are given on pages 3, 5, 6, and 9. The activities clearly relate to Instructional Objectives 1, 2, 3 and 4 respectively.

Have students work in pairs or independently. Groups larger than two are not recommended.

For Instructional Objective 3, indicate to the students those species which are cross pollinated to an appreciable degree.

Help the students carry out their own exploratory observations in such a way that they are ultimately led to trace and compare the developmental stages of the fruit in the Gramineae and Leguminosae.

C) Suggestions:

Rice, sorghum and corn are highly recommended as laboratory specimens. Rice exhibits the less common 6-staminate floret and has only rudimentary glumes. The anther dehiscent stage in sorghum is especially interesting and is worthwhile examining in the laboratory. Corn has an interesting spikelet formation in the female inflorescence that is easily observed with the dissecting microscope. Students are thus given a chance to develop some manipulative skills with the scope and the dissecting blade as well. It is a surprise to many beginning students that the corn silk is actually a style with an atypical stigmatic surface.

While a lecture-type introduction may be useful, do not extend the lecture to discuss material that is not present in the laboratory. Thus, if it is desirable to point out that wheat spikelets are sessile, have one on hand! Similarly, if it is desirable to point out that all legumes do not have a raceme type of inflorescence, have an example on hand! Items are always more relevantly discussed when real specimens are available.

Have enough plant material on hand for each student and have it clearly and correctly labeled. Students may effortlessly pick up a few scientific names during the course of the activities providing they can work with the material first-hand and providing that the scientific names seem both necessary and commonplace. An hour or so spent grouping and labeling specimens before the session will be an hour or so well spent.

PHOTOSYNTHESIS AND PRIMARY PRODUCTIVITY

OBJECTIVES:

A) Instructional Objectives:

Photosynthesis is the process by which plants remove carbon dioxide from the air to form new plant material. The photosynthetic production of plant material in crop communities is referred to as "primary productivity." Photosynthesis is driven by light energy. Since sunlight can be a limiting factor in crop communities, agronomists are often interested in assessing the effects of limited amounts of sunlight on both plant growth and primary productivity.

Seedling experiments will be prepared by the instructor for this session to study what happens when sunlight is limited by way of plant competition. The data for these experiments will be collected by the class as a whole. The session is designed to lead you to make your own growth analysis of the seedling material. By the end of the session, you should be to:

1) WRITE the basic chemical equation for photosynthesis and DESCRIBE the importance of four primary plant growth factors in the overall process of photosynthesis.

2) DEFINE crop growth rate (CGR) and leaf area index (LAI).

3) COMPARE the morphological responses of two seedling species to increasing planting density in terms of several measurable characteristics.

4) PREDICT, in the form of a hypothesis, whether or not there is a relation between crop growth rate and leaf area index and
ILLUSTRATE the test of your hypothesis with appropriate response curves.

B) Terminal Objective:

After the completion of the above growth analysis, you should be able to describe several of the effects plant competition for light can have on crop growth and productivity.

WORKSHEET:

A) Photosynthesis:

Photosynthesis is the process by which light energy is captured by plants and converted into forms of chemical energy that are used in the production of carbohydrate. Write the basic chemical equation for photosynthesis!

$$\underset{\text{(water)}}{\underline{\qquad}} + \underset{\text{(carbon dioxide)}}{\underline{\qquad\qquad}} \xrightarrow{\text{LIGHT}} \underset{\text{(oxygen)}}{\underline{\qquad}} + \underset{\text{(carbohydrate)}}{\underline{\qquad\qquad}}$$

This equation is the basis of all studies in primary productivity.

The equation, however, is deceptively simple! Photosynthesis is actually an extremely complex biophysical and biochemical process which involves many molecules. Therefore, before beginning the growth analysis exercises for this session, it is worthwhile to consider more carefully the overall process and the specialized plant structures involved.

To begin, list the three primary plant growth factors which a plant must obtain from its environment for photosynthesis to occur.

1) ______________________

2) ______________________

3) ______________________

The following pages illustrate how the photosynthetic machinery of a plant is adapted to these requirements at three different levels -- the biochemical level, the organelle level, and the organ level.

A) Photosynthesis (continued)

1) The Biochemical Level:

The first step in photosynthesis is the absorption of light by chlorophyll, a pigment that converts the light energy into chemical energy that can be used by the plant. Chemical energy is collected by energy acceptors, one of which is the molecule adenosine diphosphate (ADP). Energy acceptors are thus converted into energy carriers (eg.; ATP) which transfer the energy needed to drive the various biochemical reactions associated with CO_2 assimilation and carbohydrate production. Each biochemical reaction is catalyzed by a specific enzyme, a macromolecule composed of an ordered sequence of many amino acids (usually more than 100).

Questions:

1) A few of the many molecular participants in photosynthesis are represented in Figure 1 on page 4. Can you identify three essential mineral nutrients in the molecular structures shown?

2) Would you therefore conclude that there is a fourth environmental factor required for photosynthesis? Explain!

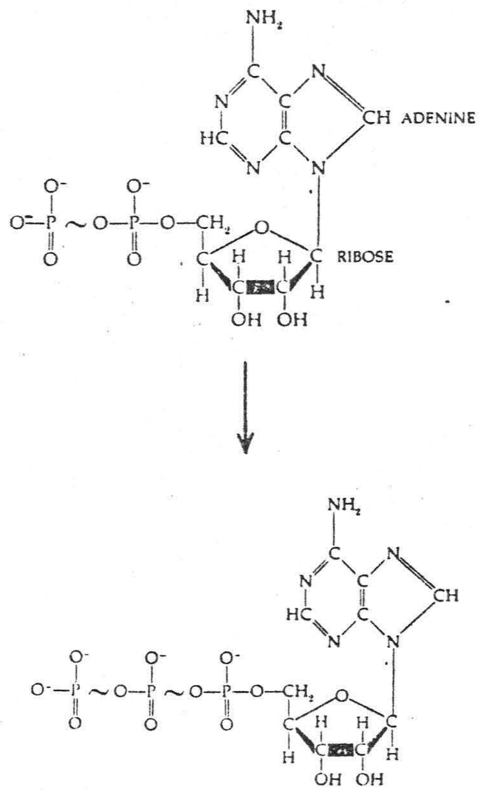
Figure 1

Molecular Participants in Photosynthesis

$nH_2O + nCO_2$

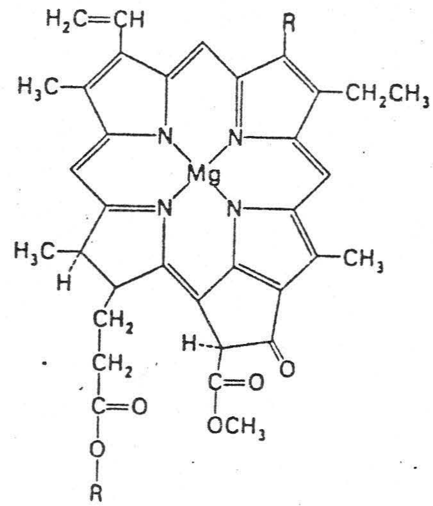
LIGHT ENERGY

Energy acceptors in the overall process of photosynthesis include adenosine diphosphate (ADP).

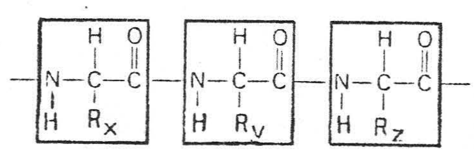


Energy carriers in the overall process of photosynthesis include adenosine triphosphate (ATP). ATP is one of several energy carriers that provide the chemical energy that is necessary for the biosynthesis of carbohydrate.

Chlorophyll receives the light energy necessary for photosynthesis.



All biochemical reactions in living organisms are catalyzed by specific enzymes, large molecules composed of an ordered sequence of many amino acids.



--am.ac.$_x$--am.ac.$_y$--am.ac.$_z$--

$(CH_2O)_n + nO_2$

Note: (CH_2O) is a simplified, or empirical, representation of a molecule that usually has five or more carbon atoms. Hence, "n" represents the number of carbon atoms in the carbohydrate produced.

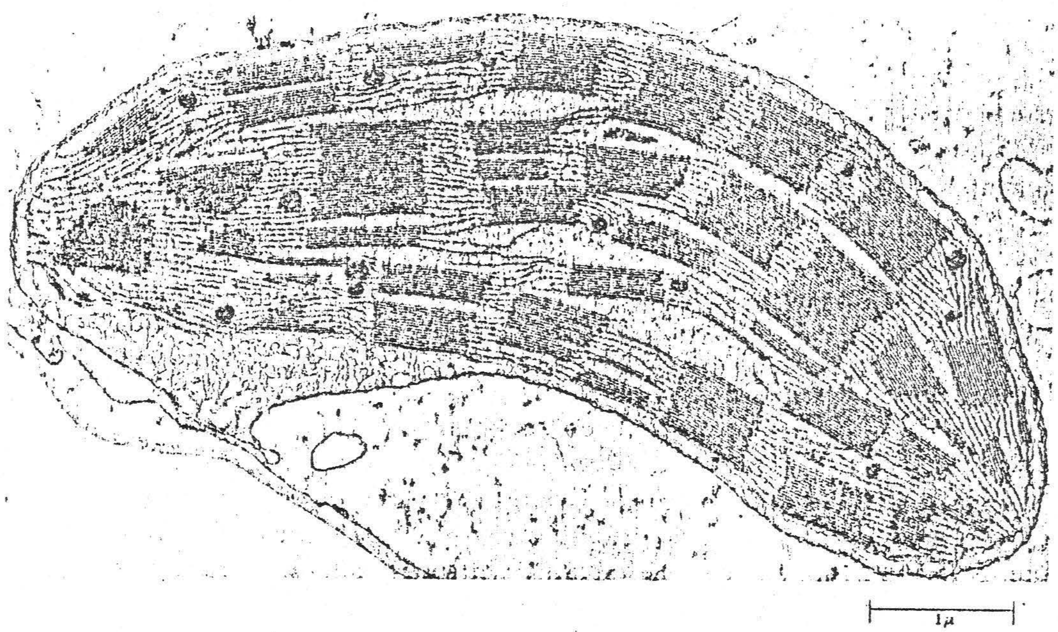
A) Photosynthesis (continued)

2) The Organelle Level -- The Role of the Chloroplast:

Photosynthesis takes place in the chloroplasts, specialized organelles that derive their name from the chemical pigment, chlorophyll. Figure 2 is a reprint of an electron micrograph of a chloroplast from a corn cell. Notice the intricate system of inner-membranes. These membranes, known as the lamellae bear the chlorophyll that absorbs the light energy needed for photosynthesis. The grana are the regions of the chloroplast where the lamella are folded and stacked. The grana look like green granules under a high power light microscope.

Figure 2

The Chloroplast;
An Organelle Specialized for Photosynthesis



Photocopy after Raven and Curtis (1970), page 79

A) Photosynthesis (continued)

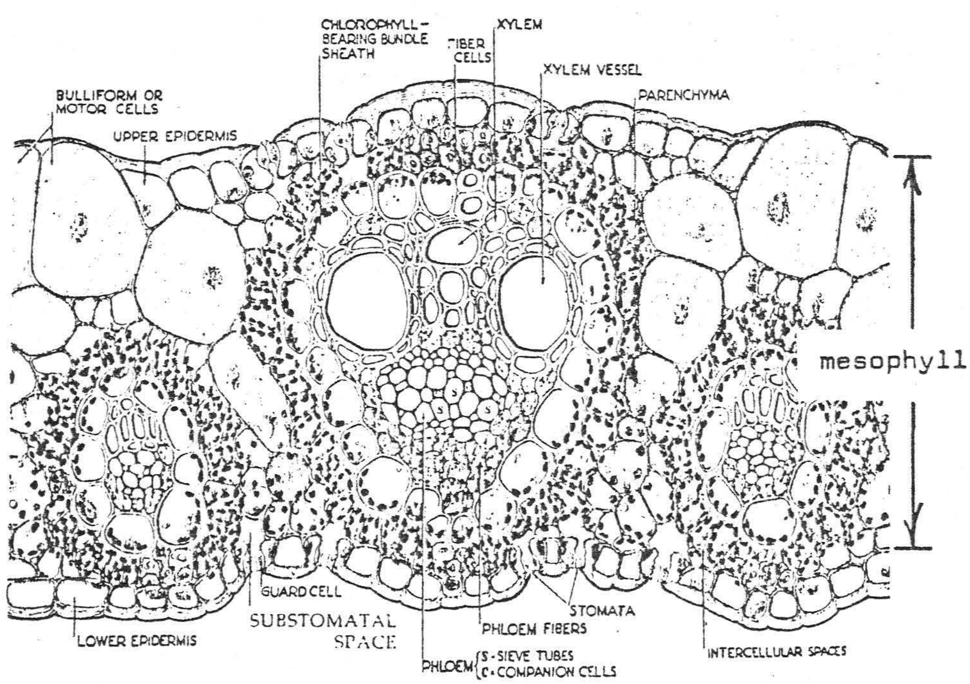
3) The Organ Level -- Leaf Structure:

Leaves are specialized to support photosynthesis and to supply photosynthetic products (carbohydrate) to the plant. Figure 4 below shows a cross-section of a sugar cane leaf. The mesophyll fills the body of the leaf and is bound by the upper and lower epidermal tissues. Water vapor, carbon dioxide and oxygen are exchanged within the substomatal cavities. Water is supplied to the leaf from the roots by way of the xylem. Photosynthetic products are transported out of the leaf through the phloem to other parts of the plant where they are used as food. Xylem and phloem elements are always found together and form the vascular bundles.

The chloroplasts are shown in Figure 4 as small dark structures within certain cells of the mesophyll. Only those cells which contain chloroplasts can carry out photosynthesis.

Figure 3

The Leaf; An Organ Specialized for Photosynthesis

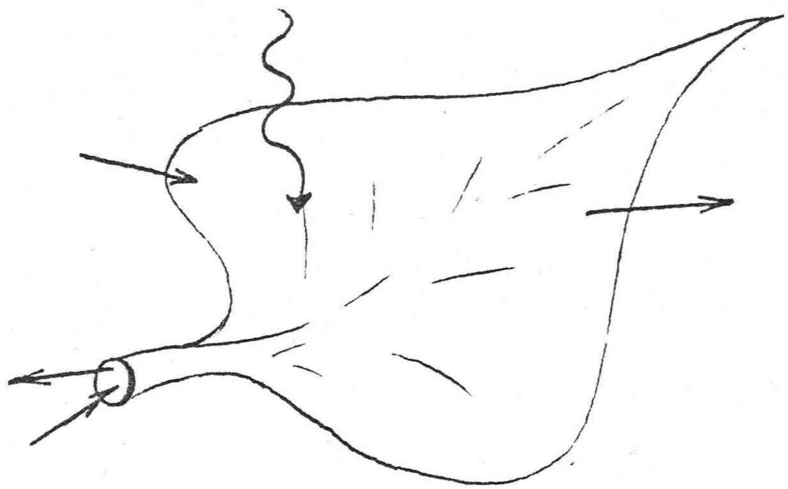


Photocopy from Martin, J. P. (1938). Sugar Cane Diseases in Hawaii. Hawaiian Sugar Planters' Association. page 28.

Figure 4

The Role of the Leaf in Photosynthesis

Complete the diagram!



Questions:

1) Can you describe the importance of four primary plant growth factors in the overall process of photosynthesis?

2) Agriculture has been defined as a strategy for manipulating the plant environment to maximize solar energy conversion into food, feed and fiber. Do you consider this an acceptable definition? Support your answer.

B) Crop Growth Rate (CGR) and Leaf Area Index (LAI):

Primary productivity refers to the photosynthetic manufacture of plant material in a crop community. About 9/10 of the dry matter produced by a crop is carbohydrate or is derived from carbohydrate material produced by photosynthesis. Only about 1/10 of a crop's dry matter is mineral material obtained from the soil. Primary productivity is therefore measured, or estimated, in terms of the crop growth rate (CGR), which is defined as:

$$\mathrm{CGR} = \frac{\text{grams dry matter produced}}{\text{(land area)} \times \text{(time)}} = \frac{\text{grams}}{(\mathrm{m}^2) \times \text{(day)}}$$

A limited supply of any one of the essential plant growth factors can affect the productivity of a crop. Light is one growth factor that has been the subject of many growth and productivity studies in crop communities. Plant competition for light not only affects primary productivity; it also affects the morphology of crop plants. Perhaps the most important morphological feature affected by light is leaf area. For the purposes of growth analysis, agronomists often look at leaf area on a unit land area basis, just as they look at primary productivity on a unit land area basis. Hence, leaf area index (LAI) is defined as a ratio:

$$\mathrm{LAI} = \frac{\text{total leaf area}}{\text{land area}} = \frac{\mathrm{m}^2}{\mathrm{m}^2}$$

C) Introduction to Growth Analysis:

Two questions might now be asked:

1) Is there a clear relationship between leaf area and crop growth?

Many agronomists have hypothesized that the more leaf area that is produced by a given crop, the better the crop's potential for photosynthesis and growth. Increasing the leaf area of a crop can be done by increasing the planting density. However, high planting densities can cause leaves to compete for sunlight and result in undesirable changes in plant morphology which impair normal growth.

2) Is the relationship (if there is one) between leaf area and crop growth the same for different species?

It is well known that different species adapt differently to different environments. Perhaps a grass species, with erect and narrow leaves, would adapt differently to high planting densities than would a legume, having horizontal and broad leaves.

Seedling experiments have been designed to allow you to investigate these questions. Sorghum (*Sorghum bicolor*) and mung bean (*Phaseolus aureus*) will be planted at different densities several weeks prior to the session. Since the seed weights and the size of the seedlings of both species are approximately the same, the growth rates of the two can be easily compared as a function of planting density.

The seedlings will be grown in $\underline{100\ cm^2}$ ($\underline{1\ dm^2}$) pots at 1, 2, 4, 8, 12 and 16 seedlings per pot. Each treatment will consist of four pots placed side by side to form a $\underline{400\ cm^2}$ treatment area. Each treatment will be replicated twice. The seedlings will be grown in the greenhouse for three or four weeks prior to the session.

C) Introduction to Growth Analysis (continued)

Some preliminary data for the growth analysis experiments will be collected by the class as a whole. To save time, each person will be assigned to make and record measurements for one or two treatments, and the data will be compiled on the blackboard. Preliminary data should be collected as follows:

1) Plant Height: Find the two tallest and the two shortest plants in the treatment(s) you are assigned. Measure the height of the upper-most part of the top leaf on all four plants from the top of the pots. Do not lift the leaves as these measurements are to be representations of the canopy height as it is displayed on the greenhouse bench. Average the four measurements! Report the result in Table 1 or 2 on page 11.

2) Fresh Leaf Weight: Detach the leaves at the leaf collar (if sorghum) or at the junction of the leaf blade and the petiole (if mungbean). Weigh all the leaves for the four plants in the treatment. Report the average weight on page 11.

3) Leaf Area: Trace each leaf onto "10 x 10 to the cm" graph paper. Make the tracings share common boarders where possible, but make sure there is no overlap. Count the number of 1 cm^2 squares enclosed by all the tracings. To save time, count those squares which are more than 1/2 enclosed. Do not count squares which are less than 1/2 enclosed. Large numbers of squares can be counted faster and with less error by marking out a rectangle of squares and multiplying the length times the width. Obtain the average leaf area per plant (to the nearest 1 cm^2) by dividing the total number of squares by four.

4) Leaf Weight per unit Leaf Area: Use 4 and 5 above to obtain this value.

DO NOT DISCARD ANY OF THE PLANT MATERIAL! KEEP INDIVIDUAL REPLICATE AND TREATMENT MATERIALS SEPARATE!

Record your results on the board and compile the class results in Tables 1 and 2. Choose two characteristics which you feel would be the most interesting to plot as a comparison of the adaptation of sorghum and mungbean to planting density. Make your plots on page 12.

Tables 1 & 2

Preliminary Data; Morphological Responses to Planting Density

Table 1: Sorghum (*Sorghum bicolor*), ______days old

Measurement	Rep.	Number of Plants per dm^2: 1	2	4	8	12	16
Plant Height (per plant)	1						
	2						
	AVGE.						
Fresh Leaf Weight (per plant)	1						
	2						
	AVGE.						
Leaf Area (per plant)	1						
	2						
	AVGE.						
Leaf Weight per unit Leaf Area	1						
	2						
	AVGE.						

Table 2: Mung bean (*Phaseolus aureus*), ______days old

Measurement	Rep.	Number of Plants per dm^2: 1	2	4	8	12	16
Plant Height (per plant)	1						
	2						
	AVGE.						
Fresh Leaf Weight (per plant)	1						
	2						
	AVGE.						
Leaf Area (per plant)	1						
	2						
	AVGE.						
Leaf Weight per unit Leaf Area	1						
	2						
	AVGE.						

Figures 5 & 6

Morphological Responses of Sorghum and Mungbean to Planting Density

Figure 5: Sorghum (*Sorghum bicolor*)

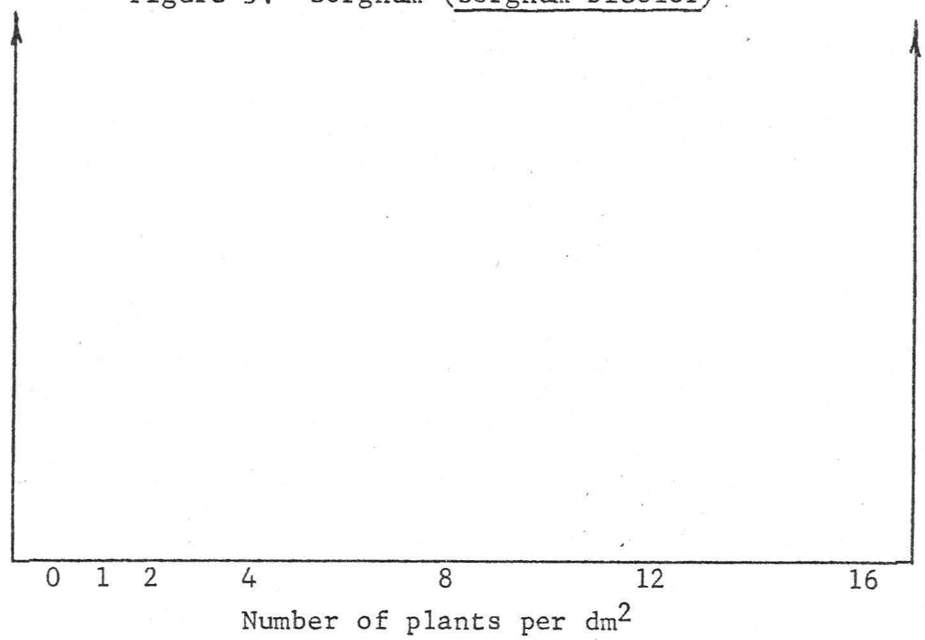
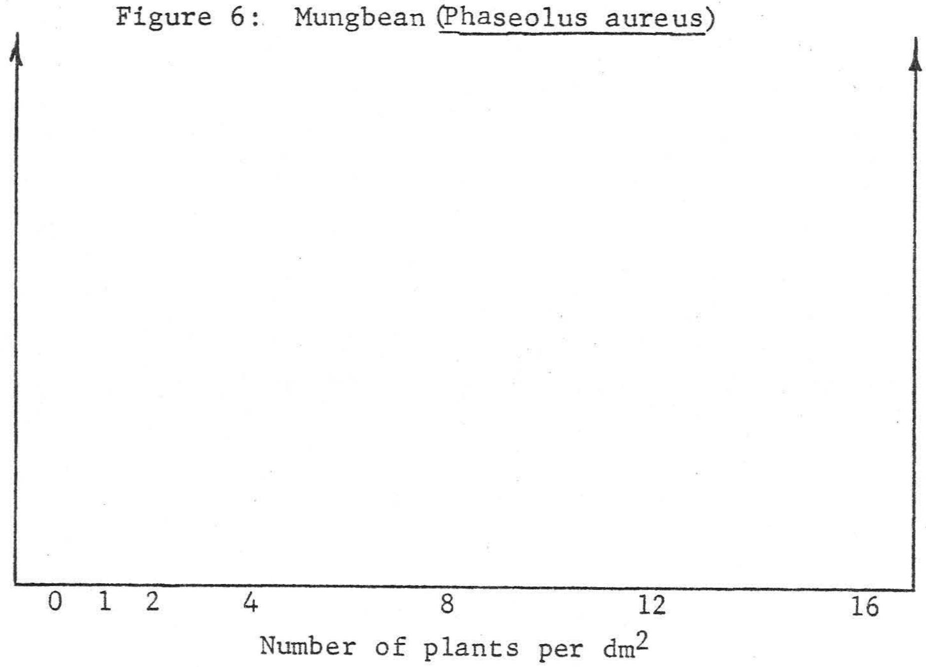


Figure 6: Mungbean (*Phaseolus aureus*)



C) Introduction to Growth Analysis (continued)

Questions:

1) Observe the plant material in the two experiments carefully. What other measurable characteristics might have been studied in addition to the data in Tables 1 & 2? (List at least three!)

2) A response in the "Leaf Weight per unit Leaf Area" is an indication of one or both of two possibilities. What are they?

If there is an appreciable response in leaf weight per unit leaf area, dry weight measurements of leaf tissue must be obtained to determine the percent (%) dry weight and to answer which of the two possibilities has (have) occurred. Collect the leaves for each treatment and put them in a paper bag for drying. KEEP REPLICATES SEPARATE! Label the bags as follows:

Plant Name -- Leaves Only
Treatment
Replicate
Your name

The dry weight data will be collected by the instructor and given to you next session. At that time you can complete the table below and draw appropriate conclusions.

Table 3

Leaf Response (% Dry Wt.) to Planting Density

Number of Plants/dm^2		1	2	4	8	12	16
Percent Dry Weight Sorghum Leaves	Rep 1						
	Rep 2						
	AVGE.						
Percent Dry Weight Mungbean Leaves	Rep 1						
	Rep 2						
	AVGE.						

C) Introduction to Growth Analysis (continued)

From your observations of the seedling material in the two experiments, and from your plots of the preliminary data, can you predict what the response of CGR and LAI to planting density might be. Write your predictions in the form of two hypotheses, each related to one of the questions posed on page 9.

1st Hypothesis:

2nd Hypothesis:

To complete your growth analysis, and to test your hypotheses, estimates of both CGR and LAI must be made.

1) Estimating CGR:

Since CGR is a measure of the rate of TOTAL dry matter production, whole plants must be sampled, dried and weighed. Collect the remainder of the plant material (roots, stems, etc.) for the SAME four plants that were chosen for sampling in each treatment. Carefully disentangle the roots and wash the planting medium from the roots as carefully and as completely as possible. Combine all of the sampled material (without the leaves) in a separate bag. Label the bag as follows:

Plant name -- Roots and Stems
Treatment
Replicate
Your Name

The dry weight data per plant will be collected by the instructor and given to you next session. You will then be asked to calculate ESTIMATES of CGR and to use these estimates to test your hypotheses.

Write the equation you will use to estimate CGR. (Remember to consider the initial weight of the seeds!) Check your equation with the instructor.

CGR =

2) Estimating LAI:

LAI can be estimated from data already obtained. Write the equation that you will use.

LAI =

Table 4

Final Growth Analysis Data for SORGHUM

Area/pot = 100 cm^2 = 1 dm^2
Initial Dry Seed Wt. = 0.03 grams/seed
Time Grown = ____ days
No. of Replicates = 2

Number of Plants per dm^2		1	2	4	8	12	16
Dry Weight Leaves per Plant (grams)	Rep. 1						
	Rep. 2						
	AVGE.						
Dry Weight Stems and Roots per Plant (grams)	Rep. 1						
	Rep. 2						
	AVGE.						
TOTAL Dry Weight per Plant (grams)	AVGE.						
TOTAL Dry Weight per Pot (grams/dm^2	ESTIMATE						
Initial Dry Seed Weight per Pot (grams/dm^2)	ESTIMATE						
CGR (grams/m^2/day)	ESTIMATE						
LAI	ESTIMATE						

Table 5

Final Growth Analysis Data for MUNGBEAN

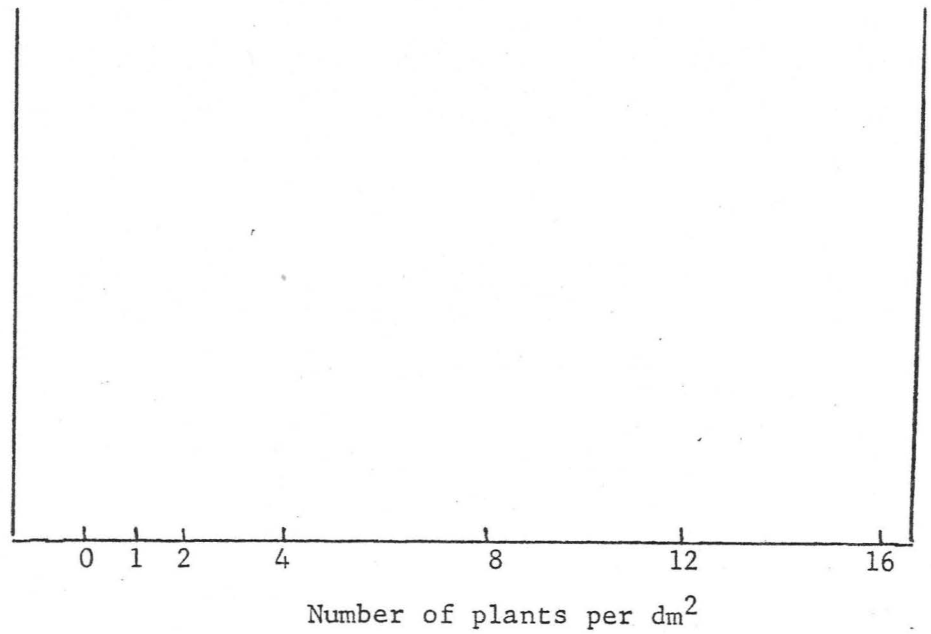
Area/pot = 100 cm^2 = 1 dm^2
Initial Dry Seed Wt. = 0.05 grams/seed
Time Grown = ____ days
No. of Replicates = 2

Number of Plants per dm^2		1	2	4	8	12	16
Dry Weight Leaves per Plant (grams)	Rep. 1 Rep. 2 AVGE.						
Dry Weight Stems and Roots per Plant (grams)	Rep. 1 Rep. 2 AVGE.						
TOTAL Dry Weight per Plant (grams)	AVGE.						
TOTAL Dry Weight per Pot (grams/dm^2)	ESTIMATE						
Initial Dry Seed Weight per Pot (grams/dm^2)	ESTIMATE						
CGR (grams/m^2/day)	ESTIMATE						
LAI	ESTIMATE						

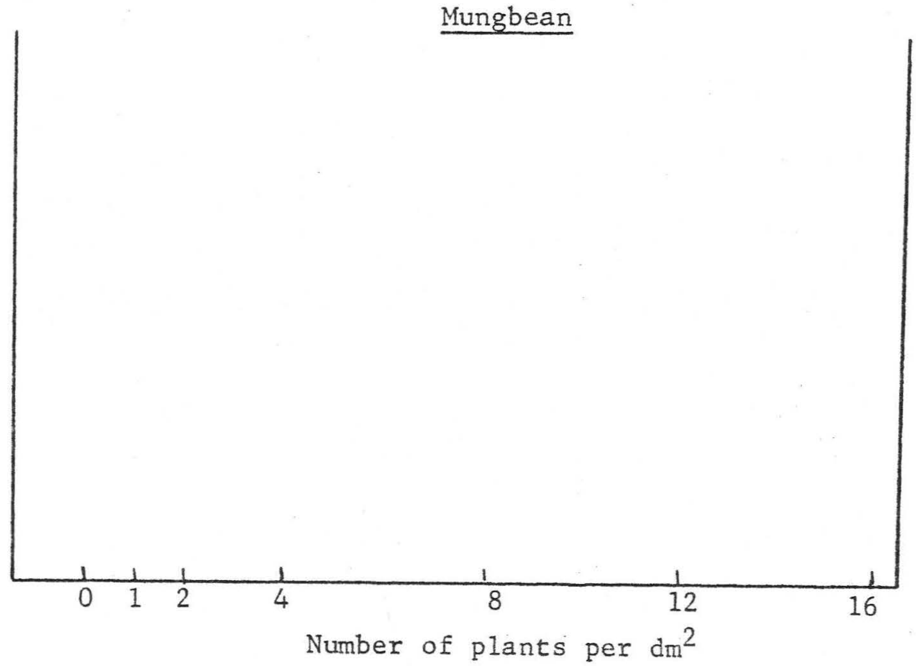
C) Introduction to Growth Analysis (continued)

Illustrate the tests of your hypotheses below by plotting response curves. Draw appropriate conclusions.

Sorghum



Mungbean



C) Introduction to Growth Analysis (continued)

Your conclusions for these two experiments might include the following: A discussion of the nature of the response curves and possible explanations. A comparison of the adaptations exhibited by both plants in response to planting density. A discussion of the optimum leaf area index as indicated by the experiments.

REFERENCES AND SELECTED READINGS:

Asimov, I. (1968). Photosynthesis. Basic Books. 193 p. An excellent elementary discussion of the carbon cycle, its chemistry, and the organelles that carry out the cycle.

Blackman, G. E. (1968). The application of the concepts of growth analysis to the assessment of productivity. In: Functioning of Terrestrial Ecosystems at the Primary Production Level, F. E. Eckardt (ed.). U. N. E. S. C. O. pp 243-259.

Hughes, A. P. (1962). Plant growth and the aerial environment. The Journal of the Australian Institute of Agricultural Science. 28:23-30.

Raven, P. H. and H. Curtis. (1970). Biology of Plants. Worth. 706 p. Section 3; "Photosynthesis and Respiration: Harvesting the Sun."

San Pietro, A., F. A. Greer and T. J. Army. (1967). Harvesting the Sun; Photosynthesis in Plant Life. Academic Press. 342 p.

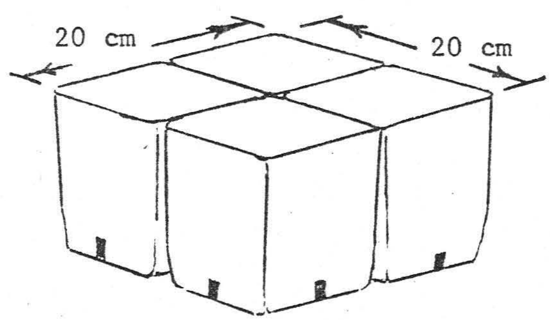
Wolf, D. D. and E. W. Carson. (1973). Growth analysis. Journal of Agronomic Education. 2:39-42.

INSTRUCTOR'S NOTES:

A) Materials and Preparation:

The planting density experiments for this session should be set up three to four weeks before class. Sorghum (*Sorghum bicolor*) and mungbean (*Phaseolus aureus*) are well suited for these experiments for several reasons. Their initial seed weights and seedling size are similar. Their leaf areas are easily measured by the conventional tracing method. Most important, both species respond well to increased planting density. Other species, however, may be equally suitable.

The seedlings are to be grown in cubic plastic pots, 10 cm x 10 cm x 10 cm, at 1, 2, 4, 8, 12 and 16 seedlings per pot. Fill 96 pots with perlite or a mixture of perlite and sand to 2 cm from the top of each pot. Arrange the pots on a greenhouse bench in groups of four to form 20 cm x 20 cm treatment areas as shown. One treatment should be assigned to each group of four pots and each treatment replicated twice.



A suggested number of seeds to be planted in each pot of a given treatment is given on page 1b. Spread the desired number of seeds on the surface of the planting medium and cover with vermiculite or peat. Water regularly until emergence and then thin the seedlings to the number of plants per pot specified by each treatment. (Note: One extra plant might be retained per pot until the seedlings are fully established.) After thinning, begin watering the treatments separately with nutrient solutions prepared to a concentration proportional to the planting density. The concentrations for each treatment and the formula for a full strength nutrient solution are also given on page 1b.

A) Materials and Preparation (continued)

Planting Requirements and
Nutrient Solution Concentrations for each Treatment

Treatment (No. plants/pot)	No. seeds/pot to be planted (suggested)	No. ml full strength nutrient solution made up to one liter
1	4	62
2	8	125
4	10	250
8	20	500
12	25	750
16	30	1000

The full strength nutrient solution can be prepared in 100-liter batches as needed at the greenhouse bench. Recommended nutrient concentrations per 100 liters are as follows:*

KNO_3	50.5 grams per 100 liters
$Ca(NO_3)_2$	82.0
$NaH_2PO_4 2H_2O$	20.8
$MgSO_4 7H_2O$	36.9
Ferric citrate	2.5
$MnSO_4$	0.223**
$CuSO_4 5H_2O$	0.024**
$ZnSO_4 7H_2O$	0.030**
H_3BO_3	0.186**
$(NH_4)_6Mo_7O_{24} 4H_2O$	0.004**
$CoSO_4 7H_2O$	0.003**
NaCl	0.585**

*From Hewitt, E. J. (1963). Mineral nutrition of plants in culture media. In: Plant Physiology Volume III, F. C. Stewart (ed.). Academic Press. pp 97-133.

**These weights are easily added to the nutrient solution as 1 ml of stock solution having micronutrient concentrations of 1000 times these weights per liter (eg.; 223 g $MnSO_4$ per liter stock solution, 24 g $CuSO_4 5H_2O$, etc.).

A) Materials and Preparation (continued)

The materials which need to be collected for the growth analysis session are:

1) Three to four week old seedlings; pots in groups of four and labeled as to

   a) species.
   b) treatment (no. plants per pot).
   c) replicate (1 or 2).

2) 30-cm rules for measuring plant height (many).

3) Graph paper, "10 x 10 to the cm", for determining leaf area (many sheets).

4) Dissecting blades or razor blades for detaching leaf material (several).

5) Balances for weighing fresh plant material to the nearest 0.1 gram (two or three).

6) Paper bags for placing samples for drying (48).

7) Stapler for closing bags.

8) Felt pens for labeling bags.

9) Trash cans for discarding planting medium.

10) Wash basins for washing plant roots.

11) Paper towels.

B) Presentation (A three-hour growth analysis laboratory):

Use the opening minutes to review the basic chemical equation for photosynthesis. The students should realize that the chloroplasts are the organelles that are specialized to carry out photosynthesis. The mitochondria might be mentioned as the counterpart to the chloroplasts and the role of each in the carbon cycle might be diagramed on the board. The students should also realize that light drives the overall process of photosynthesis, and that solar energy is the original source of the chemical energy that drives all biological systems, including the carbon cycle. The instructor may also wish to mention that marked differences in photosynthetic rates occur among species. (A suggested demonstration is described on page 1g.)

Lead the students into the growth analysis exercises by introducing the idea of plant competition. Briefly explain how the seedling experiments were designed to study the effect of plant competition for light. Have students visually examine the morphological response of the seedlings to planting density. Ask what measurable characteristics might be investigated (eg.; stem thickness, internode length, number of leaves per plant, etc.). An important inference that can be made from these observations is that light can affect leaf characteristics and therefore influence a crop's potential for primary productivity.

The growth analysis exercises for this session begin on page 10. The students should be familiar with the material on pages 1-9 before beginning the exercises.

Data collection for the growth analysis should be a group effort. Students can be assigned to individual treatments and the data compiled on the board. Tables 1 and 2 on page 11 will have to be drawn on the board for this purpose.

Only four plants, the two largest and the two smallest, are to be sampled from each treatment (i.e.; four plants from each set of four pots). This is an excellent opportunity to point out the value of "representative sampling" where complete sampling is impractical. Indeed, in actual crop communities and in field experiments, complete sampling is often impossible. From the samples which are selected, the students will obtain "estimates" of the parameters that are of interest.

Carefully supervise the students as they sample the plant material and make their measurements. Supervision is necessary to insure uniform sampling. Supervision also helps students recognize some of the short-cuts to determining leaf area by tracing (eg.; having traces share common borders where possible). Many students also need to be informed or reminded of the meaning of "significant figures." Students' data and results are often cumbersome because the numbers are stretched well beyond the last significant figure.

B) Presentation (continued)

After the preliminary data are collected and compiled on page 11, each student should choose two characteristics to plot in Figures 5 and 6 on page 12. The student thus begins his own growth analysis by making graphic comparisons of the adaptation of sorghum and mungbean to planting density.

One of the measurable characteristics included in the tables on page 11 is leaf weight per unit leaf area. A response here to planting density indicates a change in the leaf thickness, in the percent dry matter, or both. The students are asked to bag the leaf material separately for drying to determine whether or not there is, in fact, a response in the percent dry matter with increasing density.*

The students have now made enough observations to consider possible answers to the questions posed on page 9; namely:

1) Is there a relationship between leaf area and crop growth?

2) Is the relationship (if there is one) the same for different species?

Students should predict the answer to each of these questions in the form of a hypothesis. Crop growth rates (CGR) and leaf area index (LAI) have been defined for the students for this purpose. Since student hypotheses are to be tested by plotting CGR and LAI as functions of planting density, the hypotheses might be formulated as predictions of the nature of the response curves. For example:

1st Hypothesis: Leaf area per plant decreases greatly at high planting densities; therefore, LAI is predicted to increase to a maximum value and CGR will follow the same response.

2nd Hypothesis: Sorghum leaves are well suited for light interception at high planting densities; therefore, the maximum values for CGR and LAI are predicted to be higher for sorghum than for mungbean.

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*During the fall semester of 1975, students reported an increase in the percent dry weight of total plant material with increasing planting density for sorghum (6% at 1 plant/pot, 10% at 8 plants/pot). The percent dry weight of mungbean, however, remained constant at 8%. Dry weight data for leaves in these experiments would be more revealing. Some interesting discussions related to plant responses to different light environments and to these data are possible during the session and can be used to stimulate the students' interest in completing Table 3 on page 13.

B) Presentation (continued)

The student should be allowed to develop his own logic when formulating his hypotheses. The hypotheses above are merely examples of what the instructor might lead a student to write on his own. If a student is lost, review with him the types of common response curves and ask him to predict the type of response LAI and CGR will follow. That is: Will the response indicate an optimum density? Will productivity increase or decrease with increasing density? Etc.

Some students may wish to formulate more immaginative hypotheses than might be expected. Let them! Ask them to explain how their hypotheses will be tested: What will be plotted? What data will be compared? Etc. Encourage them to carry out the tests and to draw appropriate conclusions.

Students cannot plot their results until the dry weight data are collected. Students must, therefore, collect, wash and bag the remainder of the plant material for the same four plants in each treatment. Dry weight data per plant should be collected by the instructor, who can tabulate and reproduce the raw data and have it available for students to work with as homework. Students can complete Tables 4 and 5 on pages 15 and 16, respectively, and make their plots on page 17. Page 18 is provided for the student to write his conclusions.

A final discussion of the growth analysis can be conducted during the next formal class meeting.

C) Suggestions:

1) Demonstration of Photorespiration:*

The instructor may wish to set up a simple demonstration of photorespiration to complement the opening discussion of photosynthesis and the carbon cycle. The demonstration entails a number of basic concepts, including photosynthesis, respiration, and CO_2 compensation.

The demonstration might be set up at the beginning of the session. Three 1-liter wide-mouth glass jars with air-tight lids are needed. Place two 50-ml beakers in each jar and place about 30 ml of water in one of each pair of beakers. Fresh, actively photosynthesizing leaf material is needed from two species; a C_3-type, photorespiring species, and a C_4-type, non-photorespiring species. Mungbean and sorghum leaves from the seedling experiments might be used, or other species might be collected just before class. Detach the leaf material (at least 10 cm^2) and recut under water and place in the beaker containing water. Place about 5 ml of a sodium bicarbonate indicator solution (5×10^{-5} M) containing 1% (v/v) Universal Indicator (Fisher Scientific Co.) in the second beaker. Two demonstration jars are thus prepared, each containing leaf material from one species. In the empty beaker of the third jar, place about 30 ml of NaOH solution. Seal all three jars. Place under a florescent lamp.

The indicator solution will be a greenish yellow at ambient CO_2 concentrations (300 ppm). A change in color of the solution to green at concentrations in the range of the CO_2 compensation point for C_3 species (50 to 100 ppm) and to blue at concentrations in the range of the CO_2 compensation point for C_4 species (less than 5 ppm) indicates the removal of CO_2 from the air. In the jars containing leaf tissues, a change in color indicates that these tissues are photosynthetically active. The time needed for the color change will depend on the rate of CO_2 exchange with the indicator solution.

The demonstration can be set up on a side bench in the laboratory. The color change will occur first in the jar containing the NaOH solution. The color change can be hastened by occasionally (and gently) swirling the jars to mix the indicator solution. A color change should occur in all three jars during the course of the 3-hour session, provided enough actively photosynthesizing tissue is present.

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*Originally described by Wolf, D. D. and E. W. Carson. (1975). Photorespiration: A classroom demonstration. Journal of Agronomic Education, 4:113-114.

C) Suggestions (continued)

2) Alternatives to Planting Density:

The use of planting density as a variable in the seedling experiments provides a first hand demonstration of the effects of planting density on plant morphology and productivity. Students who are participating in a planting density experiment as part of their independent study project may compare the observations and results from this classroom demonstration to their own field experiment. Thus, students who discover from this demonstration that shading in a crop community may effect internode length, leaf area, etc. may be stimulated to look for similar effects in their own experiment and include a discussion of these effects in their final report.

Other variables, however, might also be excellent choices for the seedling experiments. The instructor can easily revise the WORKSHEET for this session so that the effect of such variables as mineral nutrient level, temperature, soil pH, light intensity, day length, etc. on plant morphology and productivity are used to introduce the growth analysis exercises. The instructor is referred to the article by Wolf and Carson (1973) for more suggestions in this regard.

3) Integration with Independent Study:

One or more students may wish to design, set up and maintain one or more seedling experiments (or container experiments in which the plants are grown for a longer period of time) as a part of their independent study project. These students could thus take on the responsibility of preparing the materials for this session and would also take on the responsibility of obtaining the dry weight data for the experiments, which would be reproduced by the instructor for the rest of the class. The students would submit a final report of the experiment at the end of the semester in accordance with the requirements for the completion of their independent study project.

SECTION TWO

INDEPENDENT STUDY ASSIGNMENTS

AGRONOMY 101 is designed to include an open-ended field research project as a major course activity. For this project, each student should identify a problem related to a topic of special interest to him and carry out an independent library and field investigation of the problem. The project is to be completed with a report of the investigation written in the format of the reports found in *Agronomy Journal* and *Crop Science*. The five assignments which follow are collectively intended to guide the progress of the investigation and the completion of the final report. The assignments are listed below in the order they should be completed.

PROJECT PROPOSAL

PRACTICE CALCULATIONS

LITERATURE REVIEW AND PROGRESS REPORT

PREPARATION FOR DATA COLLECTION

FINAL REPORT

Each assignment should be completed in consultation with the instructor, who will act as an advisor during the course of the semester. The instructor will return each of the first four assignments, ungraded, with suggestions for the completion of the final report.

PROJECT PROPOSAL

(First Assignment)

To begin your independent study project in Agronomy 101, you must choose a topic of interest to you and identify a specific problem for a library and field investigation. Several topics are listed below. A number of problems for investigation can be identified for any of these topics.

planting density	fertilizer management
planting methodology	symbiotic nitrogen fixation
crop-weed interactions	mineral nutrition
insect control	water management
varietal performance	environmental effects

Your field investigation is to include a plot experiment, which may be conducted as an individual project or as a group project. A "planting density experiment" will be conducted as a group project during the course of the semester, and if you have no topic of special interest, you are encouraged to participate in this experiment.

Whether or not you participate in a group project, you must identify your own problem for investigation. Many problems can usually be investigated in a given experiment, provided the problems are identified beforehand so that appropriate experimental methods can be planned.

After choosing your topic, prepare a proposal, in consultation with the instructor, to clarify the nature of your investigation. The proposal can be prepared as follows:

1) INDICATE the problem you wish to investigate during your independent study in Agronomy 101. (The simplest way to do this is to pose a question; such as, "What is the effect of soil applied 2,4-D on corn and pea seedlings?" Or, "Is plant height affected by planting density?")

2) WRITE a hypothesis for the plot experiment which you intend to conduct as part of your investigation. The hypothesis should clearly describe the following:

    a) The treatments imposed in the experiment.

    b) The measureable observations which will be collected at the end of the experiment to test the hypothesis.

3) SKETCH the layout of your plot experiment and BEGIN a detailed record of the materials, methods and observations associated with the experiment. Prepare a separate field book for this purpose.

PRACTICE CALCULATIONS

(Second Assignment)

Because large areas of land are used for field-crop production, in contrast to the small plot areas used for agronomic research, the agronomist must often convert back and forth between large-scale and small-scale units of measure. The recent acceptance of metric measuring units further demands that the agronomist be familiar with important English-metric conversions.

This assignment introduces a hypothetical field-plot experiment to allow you to run through some of the basic conversions that are normally encountered in agronomic study. The final exercise of the assignment relates to your own plot experiment. The exercises are arranged in a sequence to illustrate the following:

1) Plot experiments usually occupy only a small fraction of a hectare.

2) Small-scale experiments follow large scale recommendations.

3) Inputs for container experiments are determined on a weight basis rather than on an area basis.

4) Conversions between the metric and the English systems of measurement are often necessary.

5) Although the English measuring system is still relied upon, metric units are now used exclusively in agronomic literature.

B) Small-scale experiments follow large-scale recommendations:

1) The nutrient inputs for the preceding experiment followed the recommendations listed below. For each recommendation, determine the how much nitrogen, P_2O_5 and K_2O were applied to each 5 by 10 meter experimental plot.

Nutrient	Recommendation PER HECTARE	Recommendation PER PLOT
Nitrogen	200 kg	_____ kg
P_2O_5	300 kg	_____ kg
K_2O	250 kg	_____ kg

2) The following fertilizers were available for the experiment:

Urea	45% N
Treble superphosphate	45% P_2O_5
Muriate of potash	60% K_2O

a) How much of each fertilizer was applied to each 5 by 10 meter plot in the experiment?

b) How many kilograms (kg) of each fertilizer would be applied to a one hectare farm using the same recommendation?

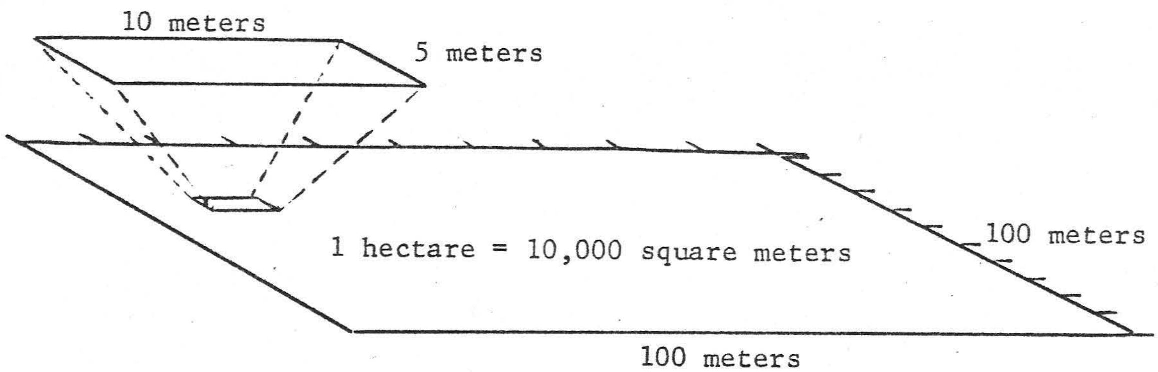
3) Atrazine, a pre-emergence herbicide, was incorporated in the surface soil just before planting at the recommended rate of 4 kg/ha of active ingredient. Assuming the herbicide was 80% active ingredient, how much atrazine was applied to each experimental plot?

A) Plot experiments usually occupy only a small fraction of a hectare:

1) A field-plot measures 5 meters by 10 meters. What fraction of a hectare is this?

1/______ = 0.______
(fraction) (decimal)

The illustration below shows the magnitude of the fractional value above. This value can be used to convert yields, fertilizer rates, etc. from a hectare basis to a plot-area basis. It can also be used to translate the results of an experiment back into the conventional hectare units.



2) Suppose a plot experiment was installed to test a claim that the yield of a new variety of sweet corn could be doubled by planting at twice the normal density. The treatments used in the experiment were 25,000 plants per hectare (normal density) and 50,000 plants per hectare. Each treatment was assigned to a 5 by 10 meter plot. What were the densities per plot? What were the densities per square meter?

#plants/ha	#plants/plot	#plants/m^2
25,000	______	______
50,000	______	______

C) Inputs for container experiments are determined on a weight basis rather than on an area basis:

1) A convenient method of determining nutrient inputs for container experiments is based on the assumption that a one-hectare plow layer (about 15 cm deep) contains two million (2×10^6) kilograms of soil. List the nutrient recommendations given on page 3 in terms of kilograms of nutrient per ONE million kilograms of soil.

2) The nutrient recommendations you have listed above are given on a "parts per million" basis. Parts per million (ppm) is used to represent a very small fraction; it is used in the same way that percent (%) is used to represent parts per hundred. Thus, the recommendation for K_2O given on page 3 can be expressed as

$$\frac{100 \text{ kg nutrient}}{1{,}000{,}000 \text{ kg soil}} = 100 \text{ ppm} = 0.0100\% = \frac{0.0100}{100} .$$

What is the conversion factor which relates kg/ha to ppm?

1 ppm = _______ kg/ha

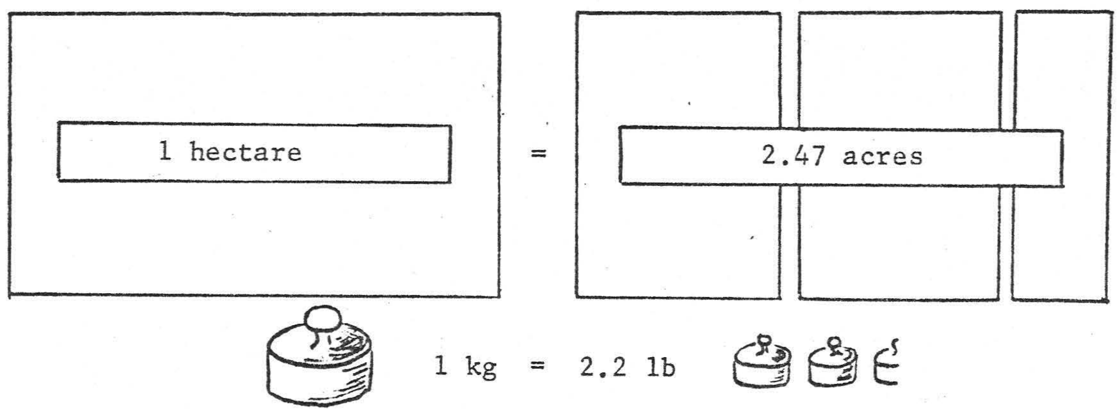
3) The sweet corn variety used in the preceding experiment was grown in pots to determine its nutrient response characteristics. Nitrogen treatments were prepared by incorporating 25, 50, and 100 ppm nitrogen in the form of urea into separate pots containing 20 kg of soil. What were the application rates of both nitrogen and urea in kg/ha and grams/pot?

Nitrogen Application		Urea Application	
(kg/ha)	(grams/pot)	(kg/ha)	(grams/pot)
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

D) Conversions between the metric and the English systems of measurement are often necessary:

1) On the farm where the sweet corn experiment was installed, no metric measuring devices were available. The 5 by 10 meter plots were, therefore, layed out in feet and their areas determined in acres. Fertilizer was obtained in 80-pound bags and fertilizer applications were calibrated in pounds per acre (lb/ac).

Given the conversion factors in the illustration below, calculate the conversion factor which relates kg/ha to lb/ac TO THE NEAREST WHOLE NUMBER. (It is fortunate that the two are related by an easily remembered factor.)



1 kg/ha = ___ lb/ac

2) List the rates of fertilizer application on both a lb/ac basis and a lb/plot basis.

Fertilizer	lb/ac	lb/plot
Urea	___	___
Treble superphosphate	___	___
Muriate of Potash	___	___

3) Could 80-pound bags of 15-15-15 fertilizer (a mixture containing 15% N, 15% P_2O_5 and 15% K_2O) be used exclusively to fertilize the plots in the experiment? How much 15-15-15 fertilizer would you have recommended for application to one plot?

E) Although the English measuring system is still relied upon, metric units are now used exclusively in agronomic literature:

1) Suppose the average yields per 5 by 10 meter plot in the sweet corn experiment were as given below. Find the corresponding yields on both a hectare and an acre basis.

Yield/plot		Yield/hectare		Yield/acre	
no. ears/plot	kg ears/plot	no. ears/ha	kg ears/ha	no. ears/ac	lb ears/ac
200	110	______	______	______	______
400	190	______	______	______	______

2) Tabulate below the planting densities and the rates of fertilizer application used in your plot experiment at the Magoon Experiment Station. List the information both in plot area and in hectare dimensions. REMEMBER TO USE ONLY KILOGRAM-HECTARE DIMENSIONS IN YOUR FINAL REPORT! Try to become familiar with the magnitude of both the planting densities and the fertilizer rates on a plants/ha and a kg/ha basis, respectively.

Experiment: ______________________________

Size of experimental plot = ___m x ___m = ____m^2 = ______ha.

Planting Densities	
#plants/ha	#plants/plot

Fertilizer Rates		
Fertilizer	kg/ha	kg/plot

LITERATURE REVIEW AND PROGRESS REPORT

(Third Assignment)

As part of your independent study, you should be reviewing agronomic publications for information related to the hypothesis of your plot experiment. You should also be keeping a detailed record of the materials, methods and observations associated with the experiment. The final report of the experiment must contain both a literature review and a brief discussion of your materials and methods.

When doing your literature research, notice the way in which literature reviews are commonly used to introduce the purpose of an experiment and pay particular attention to the brief but comprehensive style of the materials and methods section. This assignment involves the preparation of a draft for the introduction and the materials and methods section of your report. It also serves as a mid-semester progress report on your independent study.

To complete the assignment:

1) WRITE a short literature review citing published information pertaining to the hypothesis of your experiment.

2) LIST in alphabetical order by author the published works cited in your review. Use the format for literature citations found in both Agronomy Journal and Crop Science.

3) INDICATE how you found each published item (i.e.; whether from the Bibliography of Agriculture, from the Field Crop Abstracts, from the bibliography of a more recent publication, etc.).

4) STATE the specific purpose of your experiment.

5) WRITE one compendious paragraph describing your materials and methods to date. Use the simple past tense and the third person.

6) OUTLINE the materials and methods you propose to use to complete the experiment.

PREPARATION FOR DATA COLLECTION

(Fourth Assignment)

Since data collection represents an important part of your plot experiment, it is wise to define a procedure for data collection and to prepare the appropriate tables before hand. It is suggested that data collection tables be incorporated in your field book. The following pages can be used as a guide for preparing the tables.

For this assignment:

1) UPDATE the field book for your plot experiment and SUMMARIZE the state of the experiment in terms of:

   a) general crop growth characteristics including uniformity of germination, number of days from planting until flowering, branching habits, height, vigor, etc.

   b) general crop management concerns including nutrient deficiency symptoms, disease symptoms, insect damage, weed growth, etc.

2) DESCRIBE the component of yield which will be sampled during data collection and SPECIFY the number of samples (leaves, ears, stalks, etc.) to be taken from each treatment and INDICATE the criteria for the selection of samples.

3) CONSULT the instructor with regard to the preparation of data collection tables. He will assist you in drawing up the tables you need and will show you how to analyze the data you obtain in a manner consistent with your experimental design.

A) Replicates of a randomized complete block design should be dealt with separately:

If your experiment follows this design, the results of each REPLICATE should be recorded in a separate table. A suggested format for the data collection table for a single replicate is given below. Two important statistics should be included to help describe the characteristics of the replicate as a whole:

1) The replicate mean -- an average of all the observations in the replicate.

2) The standard deviation -- a measure of the variability about the replicate mean.

REP #____ Measurements and Observations (DATE)

Treatment	Material selected	Measurements "X"	Observations
total			
r			
mean			
s.d.			

Total = sum of entries = Sum(X)

r = number of entries = number of treatments

Mean = $\overline{X}_{\text{replicate}} = \frac{\text{Sum(X)}}{r}$

s.d. = standard deviation = $\sqrt{\frac{\text{Sum}(X^2) - (\text{Sum}(X))^2}{r - 1}}$

B) Replicates are not separated in a completely randomized design:

If your experiment follows this design, the TREATMENTS should be examined separately and a data collection table for each treatment prepared. A suggested format for the data collection table is given below. The two important statistics which describe the characteristics of a treatment are:

1) The treatment mean -- an average of all observations for a given treatment.

2) The standard deviation -- a measure of the variability about the treatment mean.

(TREATMENT) Measurements and Observations (DATE)

Replicate	Material selected	Measurements "X"	Observations
total			
n			
mean			
s.d.			

Total = sum of entries = Sum(X)

n = number of entries = number of replicates

Mean = $\bar{X}_{\text{treatment}} = \frac{\text{Sum}(X)}{n}$

s.d. = standard deviation = $\sqrt{\frac{\text{Sum}(X^2) - (\text{Sum}(X))^2}{n - 1}}$

C) The results of an experiment are determined by comparing the treatment means and the variability about each mean:

After the raw data for an experiment has been collected, a summary table can be made to facilitate the comparison of treatments. A possible format for a summary table is given below.

Treatment	Replicate I	II	III	...	Sum(X)	n	$\bar{X}$	s.d.
	MEASUREMENTS "X"							

The treatment means ($\bar{X}$) and the variation about the treatment means as indicated by the standard deviation (s.d.) can be used to judge the "effect" of the treatments. More sophisticated statistical analyses can be used to determine the "significance" of the treatment differences. However, for your experiment you need only analyze your data in terms of treatment means and standard deviations. (Consult the instructor if you are unfamiliar with the meaning of standard deviation.)

Note well: Raw data should NOT be included in your final report. The experimental results should be expressed in terms of the treatment means, which can be tabulated or presented graphically. Notice how experimental results are commonly presented in the literature.

FINAL REPORT

(Final Assignment)

The essential features of the final written report of your plot experiment are described in this assignment. The layout given here represents the standard format for a scientific report. Much of the material which you will include in this report has already been dealt with in the preceding assignments.

Introduction

This section should lead the reader to the purpose of the experiment you have conducted. A common practice is to note the general importance of the research topic in the first sentence (or first few sentences) and then summarize what is known about the topic as reported in the literature. The purpose of the experiment is usually given after the necessary background information has been layed out for the reader and usually comes at the very end of the introduction.

Materials and Methods

This section describes the entire experimental procedure in such a way that the experiment can be repeated by other researchers. Indeed, experiments must be repeatable if they are to represent valid scientific research. Materials and methods should be correctly described by standard nomenclature; thus, plant material should be described by scientific name and variety (eg.; *Glycine max*, var. "Kahala"), the source of the plant material identified by name (eg.; Dept. of Horticulture, Univ. of Hawaii), the soil type described in terms of its classification and fertility (eg.; Makiki stoney clay loam, neutral pH, high base status), and so on. The time of planting and harvesting, the plant material selected for measurement, and the specific measurements which were made at the close of the experiment should also be described in this section.

Results and Discussion

The results of an experiment should be presented in a summary form. Graphs or tables are recommended depending on which best illustrates the test of the experiment's hypothesis. Graphs are recommended if they illustrate particular response characteristics. Tables are recommended if treatment differences are the principle concern. Raw data should NOT be included among the results and only mean (average) values should be used in the graphs and in the tables as these are the best representation of treatment effects.

Results and Discussion (continued)

The results of an experiment should not be recapitulated in the text of a report. Results should be presented once only and immediately followed by an interpretation. The discussion should include an evaluation of the results as compared to the findings of other researchers. The discussion should ultimately lead to a conclusion. For agronomic reports, the conclusion may very well be a recommendation based on the results of the experiment.

Literature Cited

All the information included in the report which is from a source other than the writer should be designated as such by appropriate citations. The format for literature citations used in Agronomy Journal and in Crop Science is recommended. Citations can be listed by author in alphabetical order and can be referred to in the report by number (24) or by author and year (Smith, 1969). Correct journal abbreviations should be used if journal titles are not written in full. One or the other should be used consistently. If texts are cited, their titles should be written in full and underlined.

Note: Feel free to consult the instructor at any time with regard to your report. You are encouraged to present an outline or a rough draft and ask for comments and suggestions before making the final written copy.